How to guide effective student questioning?

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Design and evaluation of a principle-based scenario for teacher guidance

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Preface

....We shall not cease from exploration
And the end of all our exploring
Will be to arrive where we started
And know the place for the first time....
Eliot T.S. (1942). Little Gidding V

One day, during my History studies at the University in the late 1980's, I found a scrap of a newspaper on the doorstep of my house. Instead of just throwing it away, I took a moment to take a quick glance at it. To my surprise it contained a poem of T.S. Eliot. I was struck by its mysterious message. I decided to copy the poem and kept it for years on my pin-up board. In retrospect, it has become clear to me that this wonderful poem describes my personal motives to deepen my knowledge about the subject of this thesis.

When I became a primary school teacher in 1997, I quickly discovered that there was little opportunity for pupils to explore their own interests. However, the idea of only "spooning" knowledge was not very appealing to me. Gradually, I started to experiment with forms of education in which students could explore their interests by self-formulating and investigating questions. Even though this type of teaching required more effort from me, the reward was worth it, for I observed that pupils became more intrinsically motivated for learning. Over the years I managed to persuade my colleagues to experiment with similar teaching methods, because of the motivational effect on the pupils. At that time this question-driven approach seemed rather successful at my primary school.

In 2007 I made a career move and joined Teachers College for Primary Education. This move offered me interesting chances to share my teaching experiences and opportunities to foster question-driven education. However, when I visited my former primary school two years later, I found out most student questioning had disappeared. I was very much surprised, for I knew these colleagues to be capable teachers who were highly motivated to foster active learning. Something had happened that made them decide that question-driven teaching was no longer feasible. Determined to find out what had happened and how to resolve this, I decided to start research into teacher guidance of student questioning. That was the start of a quest which has led to this thesis.

Now, many years later, I have come to understand why question-driven teaching and learning can be so challenging for teachers and what kind of support seems to be necessary to make it a success. I have arrived at the beginning, but it seems as if, I see it for the first time.

Contents

Chapter 1

Introduction to thesis

1.1 RELEVANCE OF STUDENT QUESTIONING

The use of questions has a long tradition in teaching and learning. One of the first recorded examples was of the ancient Greek philosopher Socrates (470-399 BC). Socrates considered asking questions as the essence of teaching and the basis of his Socratic method. His student Xenophon recorded the following dialogue with Socrates: "Does teaching consist in putting questions? Indeed, the secret of your system has just this instant dawned upon me. I seem to see the principle in which you put your questions. You lead me through the field of my own knowledge, and then by pointing out analogies to what I know, persuade me that I really know some things which hitherto, as I believed, I had no knowledge of " (XIX: 24-25). Nowadays, modern 21th century teachers still ask many questions for several purposes in their classrooms. Teachers ask questions to raise students' interest for a topic, to activate prior knowledge, to check procedural understanding, to monitor learning outcomes, and to exercise classroom control (e.g. Rop, 2002).

However, in this long tradition both Socrates and modern teachers illustrate an important observation: it is the teacher who poses the questions. In fact, Reinsvold and Cochran (2012) show that teachers dominate questioning to such an extent, that teachers ask over 95% of all questions in class. As a result teachers marginalize student questioning in the classroom discourse (Dillon, 1988a; Eshach, Dor-Ziderman, & Yefroimsky, 2014; Van der Meij, 1998). We face a situation in which: "Those who ask the questions in school - teachers, texts, tests- are not seeking knowledge, while those who would seek knowledge- students- are not asking at all. Classrooms are full of questions but empty of inquiry" (Dillon, 1988b, p.115).

Although in classrooms multiple types of student questions might be raised, the focus in this thesis is on Sincere Information Seeking (SIS) questions. We define SIS questions in this study as questions raised by students about a general area of knowledge in order to enlarge their knowledge base or to resolve cognitive conflicts (Jirout & Klahr, 2011; Van der Meij, 1994). This in contrast to, for example, academic help-seeking questions which request clarification or assistance from a teacher or peers with the aim to resolve problems in completing academic tasks (Karabenick & Newman, 2006). SIS questions express the genuine interest and intrinsic motivation of students to inquire into a topic (Graesser & Wisher, 2001). Therefore, in this study student questioning is operationalized as students asking SIS questions.

Student questioning in classrooms appears to be inhibited by several causes. In the first place, many teachers use the typical Inquiry-Response-Evaluation (IRE) pattern in classroom discourse (Cazden, 2001; Lemke, 1990). Unfortunately, this type of teacher-student interaction reinforces the dominance of teacher questioning over student questioning (Reinsvold & Cochran, 2012). A second major cause for absence of student questioning seems to be the teachers' norms about the desirability of student questioning in class (Eshach, Dor-Ziderman, & Yefroimsky, 2014). In many classrooms students seem not to be encouraged to ask questions (Chin, 2001). Too often student questioning is seen by teachers as disrupting the coverage of curriculum content (Wells, 2001). Some teachers even perceive questioning as “threatening the teacher’s control of classroom events” (Rop, 2002, p.718). Another potential reason for discouraging student questioning is, that it might challenge the teacher’s domain knowledge, and in that sense also his authority as an expert, for many teachers believe they have to know all the answers to questions raised (e.g. Zeegers, 2002). A third cause for limited student questioning seems to be peer pressure. In some classrooms, asking a question is considered to be a symptom of a lack of understanding (Biddulph, 1989). Therefore, a student who asks questions might subsequently face mockery from his peers. Another form of peer pressure is the social atmosphere which forces curious students to abandon their questioning for social conformity (Shodell, 1995). These students face unwilling peers because “too many questions might take too much valuable class time and might actually hurt test grades if the teacher tries to fit SIQ’s into an all-ready over full course schedule” (Rop, 2003, p.27)

The marginal position of student questioning in class is in sharp contrast with the esteemed importance of student inquiry in education, as emphasized by many policy makers and educational scientists worldwide (e.g. Bereiter, 2002; NRC, 2000; Osborne & Dillon, 2008; Rocard et al. 2007). Influential organizations as UNESCO (2005), the World Bank (2008), the European Commission (2011), and the National Research Council (2012) have argued that Inquiry-Based Learning (IBL) is one of the important strategies to prepare students for their futures in the fast evolving global society of the 21th century. In IBL students investigate authentic problems or phenomena, which supports them to acquire various inquiry and social skills, as well as develop an inquisitive stance (Minner, Levy, & Century, 2010; Pedaste et al., 2015). Learning to ask questions is at the heart of IBL, for questioning focuses students’ attention to what is yet unknown and requires investigation (NRC, 2000).

The reason that prominent organizations and scholars promote student questioning is, that it has multiple educational benefits for both learning and teaching. First, student questioning fosters intrinsic motivation, for it allows students to set their own learning purposes (Gillespie, 1990; Scardamalia & Bereiter, 1992), which increases the motivation to pursue inquiries (Abrandt-Dahlberg & Öberg, 2001; Wells, 2001). According to the Social Determination Theory of Ryan and Deci (2000) intrinsic motivation for learning will increase if students are allowed and perceive more autonomy, and are supported in their perceived competence. Student questioning allows both autonomy, by acknowledging the personal need for seeking understanding, and the development of competence, by letting students pursue inquiries of their own interest. Second, student questioning is claimed to support knowledge construction because asking questions is a vital part of information seeking, and requires a conscious effort by the learner to identify cognitive conflicts or knowledge gaps in his or her prior knowledge (Farmer, 2007; Graesser & McHanen, 1993; Pardo & Bakes, 2015; Ram, 1991). Finally, student questioning is considered to be an effective metacognitive strategy which helps learners to monitor and evaluate their levels of understanding (Scardamalia, 2002; Veenman, 2004). It supports forms of higher level thinking such as analyzing, reasoning, and hypothesizing (Graesser, Baggett, & Williams, 1996). Moreover, Chouinard, Harris, and Maratsos (2007) suggest that, in general, student questioning seems to be the basic strategy for young children to seek knowledge about the world.

Besides the benefits student questioning seems to have for constructivist learning, research shows that it can support teaching in several ways. Teachers have been found to use student questioning to: (a) diagnose students' level of understanding, (b) monitor their students' ways of thinking, (c) enhance inquiry, and (d) evoke critical reflection (see for an extensive review Chin & Osborne, 2008). Therefore, student questioning is considered to be a potential resource for teaching students to practice self-regulated learning and acquire knowledge about the world.

To exploit its potential, various scholars have developed instructional strategies to foster student SIS questioning, such as: "Open Inquiry" (Bianchi & Bell, 2008), "Fostering Communities of Learners" (Brown & Campione, 1994), "Question-driven Problem-based Learning" (Chin & Chia, 2004), the "Laboratory School" (Dewey, 1938), the "Question-driven Classroom" (Shodell, 1995), "Knowledge Building" (Scardamalia & Bereiter, 1991, 2006), and "Classroom as Community of Inquiry" (Wells, 2001). Two examples can illustrate this. Shodell (1995) experimented to make the scientific questioning a central part of the scientific curriculum. In his approach every student had an active role as questioner. To elicit student questions, Shodell confronted his students in his introduction courses on Biology in University with several scientific, pseudo-scientific and non-scientific statements. The students were asked to raise several critical questions about these statements, as a requirement of the course. By discussing the students' questions and methods to investigate them, Shodell introduced students to both subject matter and the scientific process by which understanding about this subject matter can be developed. A second example is taken from the work of Scardamalia and Bereiter (1991, 2006). Over the course of years, they developed a digital learning environment, called Knowledge Forum, which supports collective inquiry in primary education. In Knowledge Forum students can bring in their questions and their ideas. Subsequently, students collaborate in inquiry and discussion to improve their theories and to evolve their knowledge about the subject. Summarized, although some examples can be found of supportive environments for questioning, in many classrooms student questioning is still found to be rare (Eshach, Dor-Ziderman, & Yefroimsky, 2014; Reinsvold & Cochran, 2012).

1.2 EFFECTIVE STUDENT QUESTIONING

To change classroom practice and tap into the potential of student questioning, teachers have a pivotal role. A change in teachers' pedagogical behavior seems prerequisite to overcome the challenges that inhibit student questioning. To alter stifling IRE interaction patterns, Chin and Osborne (2010) suggested that teachers could actively support more open forms of classroom discourse, which afford student questioning. Busching and Slesinger (1995) showed how teachers could change classroom culture by showing their own personal curiosity, sharing personal SIS questions, and thus modeling social acceptable questioning behavior. To address peer pressure, teachers might promote a question friendly classroom culture by a) acknowledging potential in each student's question (Beck, 1998), b) organizing opportunity for inquiry into these questions (Lehrer, Carpenter, Schauble, & Putz, 2000) and c) supporting mutual responsibility for questioning and inquiry (Zhang, Scardamalia, Reeve, & Messina, 2007).

Next to these pedagogical challenges, teachers have to overcome another major obstacle which obstructs student questioning. Wells (2001) and Lin, Hong, & Chen (2009) noted that many teachers feel pressured "to cover the curriculum". In this thesis the curriculum is defined as a set of predetermined learning goals established by national standards, school systems, syllabi and/or teachers. Self-formulated student questions, however, might not necessarily address curriculum goals. Many teachers worry that unsolicited student questioning might obstruct coverage of all curriculum topics and attainment of curricular objectives (Wells, 2001; Lin, Hong, & Chen, 2009). Rop (2002) shows that teachers, therefore, prefer direct instruction in order to achieve curriculum goals. Teachers sometimes even discourage spontaneous student questioning to prevent disruption of planned lessons.

Facing these challenges, teachers are seeking support that enables them to guide *effective student questioning*, defined as guiding students to cover and master curriculum content by raising and inquiring into self-formulated SIS questions. Although many studies pay attention to how teachers can elicit and train student questioning (Chin & Osborne, 2008), it remains unclear how teachers might align student questioning with attaining curricular objectives.

1.3 REQUIREMENTS FOR TEACHER GUIDANCE

Freedom for students to raise a diversity of questions, varying in topic and quality, seems an important prerequisite to encourage student questioning. First and above all, a positive welcoming attitude of teachers to all student questions is essential (Beck, 1998; Brown & Campione, 1994). Teachers need to take into account that initial student questions might not yet be properly phrased or insufficiently focused for inquiry (Tan & Seah, 2011). Dismissing or correcting initial questions, however, stifles student questioning (Shodell, 1995, Zeegers, 2002). Rather, a more fruitful approach seems to be to seek the potential for learning, when discussing questions in class (Beck, 1998; Busching & Slesinger, 1995). Zeegers (2002) and Hume, (2001) find that students are more willing to raise questions, when their questions are regarded as important contributions to the classroom discourse, even when not yet properly phrased. Moreover, Van Tassel (2001) shows that students are more likely to be motivated for questioning if they can raise SIS questions which are connected to their personal interests and experiences. Because students are expected to differ from each other in interests and levels of understanding, their SIS questions will consequently differ in topic and quality (e.g. Hume, 2001). Teachers, therefore, will need to facilitate a variety of student questions in class.

Offering freedom to students will not suffice, however, to support effective student questioning. Students will also need structure to raise investigable questions that address both the width and depth of the curriculum. For example, multiple studies show that many of students' initial questions seem to be both unfocused and uninvestigable (e.g. Biddulph, 1989; Chin & Kayalvizhi, 2002). Zeegers (2002) note that it seems to be difficult for many primary students to phrase initial questions which focus on their interests and which facilitate feasible investigations. Tan and Seah (2011) suggest that this is mostly due to students' developing literacy and inquiry skills. Therefore, teachers need to provide structure to guide students' initial questions, so that they take on an investigable form without losing the students' original intent and motivation.

Next to support for formulating questions, students need structure to explore the width and depth of the curriculum. Coverage of the width of the curriculum seems to be challenged by the divergent interests of students, due to personal preferences and the general popularity of certain topics, as found by Baram-Tsabari, Sethi, Bry, and Yarden (2006). This diversity in questioning might easily lead to partial knowledge construction for the individual student, and fragmented overviews of (sub-) domains on the collective level of the classroom curriculum. Therefore, Bereiter (2002) suggests that students need a shared conceptual structure which connects all student questioning, and which makes the exchange of findings meaningful to them.

Finally, students also need structure to acquire more in-depth knowledge of the curriculum. Students are expected to develop conceptual understanding in which they relate concepts with prior knowledge and different concepts to each other (Graesser & Wisher, 2001). However, De Vries, Van der Meij, and Lazonder (2008) found that unguided student questioning is seldom connected to prior knowledge, and seems to be predominantly factual rather than conceptual. Therefore, students need a pedagogical structure, which transcends the mere exchange of learning outcomes. Scardamalia (2002) contended that students should be supported in sustaining the inquiry by building upon each other's questions, and raising follow-up questions. This process of progressive inquiry will lead students to a deeper conceptual understanding (Hakkarainen, 2003).

To balance the freedom for a variety of questions with the structure to attain curricular objectives, is arguably teachers' greatest challenge in guiding student questioning (cf. Brown, 1992). When willing to foster student questioning, teachers thus face the challenge to organize structured freedom that supports effective student questioning. In this challenge, teachers need to take several aspects for guidance into account. First, teachers need to organize a welcoming classroom atmosphere to motivate students to raise their questions (Shodell, 1995; Van Zee, Iwasyk, Kurose, Simpson, & Wild, 2001). Second, to focus student questioning on curriculum topics, teachers should align this subject matter to students' prior knowledge and interests (Hume, 2001; Zeegers, 2002). Third, to engage all students in questioning, a variety of questions in quality and topics needs to be facilitated (Busching & Slesinger, 1995). Fourth, to support focus and feasibility of student questions, teachers need to seek potential in all questions and discuss their meaning and intent with the students (Beck, 1998). Fifth, to cover the width of the curriculum, teachers need to organize a meaningful exchange of findings to build collective knowledge about the topic under study (Scardamalia & Bereiter, 2006). And finally, progressive inquiry should be promoted to sustain and deepen student questioning and conceptual understanding of the curriculum (Hakkarainen, 2003). To our knowledge, there is no existing method or strategy which can support teachers to meet these challenges. Therefore a pedagogical design is needed that both provides freedom for a variety of student questions as well as provides structure to attain curricular objectives.

1.4 MIND MAPPING AS VISUAL TOOL TO SUPPORT STUDENT QUESTIONING

In some of the previous mentioned instructional strategies to foster student questioning, teachers used visual tools to support the questioning process, for example the "graphical views" in Knowledge Forum (Scardamalia & Bereiter, 2006). Three types of visual tools can be identified in the literature, when comparing their functions for guiding student questioning. *Simple visual tools* mainly have the function to support the sharing of questions and/or findings. More *advanced visual tools* do not only support sharing questions and/or findings, but are also used to organize and refine questions or transform findings into graphical representations. The most *complex visual tools* have multiple functions. In addition to sharing, organizing, and refining questions as well as exchanging, and transforming findings, complex visual tools also provide a flexible structure for elaborating knowledge construction. Complex visual tools support emergent questioning and lines of inquiry as well as support organizing peer support and feedback. A complex visual tool seems most appropriate for guiding effective student questioning, because teachers need a flexible tool that supports them in guiding both individual student questioning and collective knowledge building.

Two complex visual tools might support guiding effective student questioning: mind maps and concept maps. A mind map is a radial visual tool in which concepts are structured hierarchically or associatively in branch-like colored shapes, often supplemented with corresponding images (Davies, 2011). A concept map has a hierarchical tree shape with super- and subordinate parts, and is characterized by the cross links which describe the relations between concepts (Novak & Canãs, 2006) . Mind maps and concept maps share specific characteristics, that make them particularly suitable for guiding effective student questioning. Both have a flexible structure, which facilitates a hierarchical categorization of domain content into core concepts, subordinate concepts and details or examples (Eppler, 2006). Both visual tools support recording, exchanging, and comparing information and therefore can visualize prior knowledge and subsequent student questioning (Davies, 2011; Shih, Nguyen, Hirano, Redmiles, & Hayes, 2009). They both support quick elaborations and allow for continuous alterations in their conceptual structure, thus visualizing if and to what extent student questioning has been effective and the core curriculum has been attained.

However, mind mapping seems more aligned to the requirements of guiding effective student questioning in primary education for several reasons. Mind mapping is relatively easy to learn and was found to be more accessible for the target group in use (Eppler, 2006; Merchie & Van Keer, 2012). Moreover, mind maps have a more open structure and allow for exploration of relevant concepts and their relations, while concept mapping is more formal and focusses on the exact nature of relations between concepts (Eppler, 2006). Furthermore, only a limited set of rules is required for constructing a mind map. This lowers the cognitive load in construction, and makes them more valid for novice learners to represent their knowledge structures. This is congruent to findings of Wetzels, Kester, and Van Merriënboer (2011), who found that to effectively activate prior knowledge of novice learners with visual tools, the cognitive load of the visual tool should be limited. A pilot study showed that mind mapping has the potential to support both students and teachers in primary education to visualize prior knowledge, raise relevant student questions, and exchange findings (Stokhof, Sluijsmans, Van Vlokhoven, & Peters, 2012).

1.5 AIM OF THIS THESIS

The general research objective in this thesis is to address a practical need of primary school teachers to align freedom for student questioning with attainment of curricular objectives. To achieve this, both a practical solution for guidance of effective student questioning needs to be developed, as well as, theoretical understanding of the factors which influence the effectiveness of this solution. The main research question of this thesis is: *How to support teachers to guide effective student questioning?* Based on the promising findings of mind mapping as a complex visual tool, which supports both structure and freedom required for effective student questioning, this thesis explores how mind mapping can be integrated in the practical solution.

The method of this thesis can be characterized as educational design-based research. Design based research is “a methodological approach that supports the exploration of educational problems and refining theory and practice by defining a pedagogical outcome, and then focusing on how to design an intervention that supports the outcome” (Kennedy-Clark, 2013, p.109). Then, design-based research can be “used to systematically test the effectiveness of an intervention so as to address the complex and real learning problems that appear in naturalistic contexts and to enrich or validate existing theories” (Jen, Moon, & Samarapungavan, 2015, p.191).

The research that is presented in this thesis has five common characteristics of design-based research, as identified by Anderson and Shattuck (2012). First, it is situated in a real educational context of two primary schools. Second, it focuses on design and testing of a significant intervention to support guidance of effective student questioning. Third, mixed methods are used to collect both qualitative and quantitative data. Fourth, the design was developed in multiple iterations during four years. Finally, the focus is not only on practical solutions but also on theoretical understandings about teacher guidance of effective student questioning. By choosing design-based research as methodology we aimed to develop both a practical solution for a relevant practitioners’ concern, as well as, theoretical insights about design principles used and the conditions under which the solution might be effective (cf. Plomp & Nieveen, 2009).

The sequence of studies in this thesis follows the stages in design-based research as described by McKenney, Nieveen, and Van den Akker (2006), and Schoenfeld and Conner (2009). It starts with a *validation* study. The validation study aims to identify the design principles for guidance of effective student questioning in the literature. The second stage in design-based research is a *development* study. In this thesis the development study concerns the cyclic development and testing of a principle-based scenario to support teacher guidance of effective student questioning in two pilot schools. To evaluate the quality of the scenario, the relevance, practicality and process validity for teachers is evaluated in each iteration. After the validity of the principle-based scenario for teacher guidance is confirmed, an *effectiveness* study will be conducted. The effectiveness study aims to assess the product validity of the scenario, operationalized as student learning outcomes. The last study in this thesis is an *implementation* study. The implementation study researches if and to what extent the scenario will be adopted or rejected by teachers beyond the original development context. To determine its potential for further implementation, the scenario was trialed by multiple teachers in various primary schools.

1.6 STRUCTURE OF DISSERTATION

The structure of the thesis is as follows:

In Chapter 2 the validation study is presented. This chapter describes a literature review that sets out to identify design principles for guiding effective student questioning. We will examine 36 studies to answer the following research question: *Which emergent themes with respect to guiding effective student questioning in primary school classrooms can be derived from the literature?*

In Chapter 3 the development study is presented. The chapter describes the design and small-scale implementation and evaluation of a principle-based scenario for teacher guidance of effective student questioning. The scenario was developed in four consecutive iterations of design-implementation-evaluation and redesign (cf. Nieveen, 1999). The focus in this study is on evaluating the relevancy, practicality, and process validity, operationalized as the effectiveness of the scenario in terms of teacher guidance. In this study the following research question is addressed: *What is the relevance, practicality and effectiveness of digital mind mapping in a principle-based scenario for guiding effective student questioning?*

In Chapter 4 the effectiveness study is presented. The focus in this study is on the product validity operationalized as the effectiveness of the scenario in terms of student learning outcomes. The research question is: *To what degree do students attain curricular objectives, operationalized as (1) learning a core curriculum, (2) elaborating on this core curriculum, and (3) refining the conceptual structure of their knowledge, when teachers guide student questioning by means of a mind map supported scenario?*

In Chapter 5 the implementation study is presented. This fourth study addresses the large-scale implementation of the scenario in various primary school contexts. The focus in this study will be on the robustness of the scenario when its use is scaled up by introducing and trialing the scenario in 23 primary schools. The research question is: *What is the robustness of a principle-based scenario for guiding effective student questioning?*

Chapter 6 gives a resume of results and conclusions of all four studies to answer the main research question. Furthermore, several issues for discussion, valorization, and further research are raised.

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Chapter 2

How to guide effective student questioning: A review of teacher guidance in primary education

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ABSTRACT

Although the educational potential of student questions is widely acknowledged, primary school teachers need support to guide them to become effective for learning the curriculum. The aim of this review is to identify which teacher guidance supports effective student questioning. Thirty-six empirical studies on guiding student questioning in primary education were analyzed. Four emergent themes for teacher guidance of effective student questioning were identified in the data: first, guiding effective student questioning requires confident teachers, who create a supportive classroom culture for question generation and acknowledge the potential in students' initial questions; second, defining a conceptual focus supports teachers in aligning student questions to curricular goals; third, organizing collective responsibility for the question process in the classroom fosters effective student questioning; and fourth, teacher guidance is supported when the process of questioning is visualized on a collective platform.

2.1 INTRODUCTION

Although the use of questions in education has a long tradition, in this tradition teachers are in control of questioning, whereas students are mainly expected to provide answers (Dillon, 1988). Only since 1990 has evidence accumulated that asking questions is an important (meta-) cognitive strategy for students which supports active learning and knowledge construction (Graesser & Wisher, 2001; Veenman, 2004). This review focuses on student questioning in primary education, defined as students generating, formulating, and answering Sincere Information Seeking (SIS) questions. We define SIS questions as questions raised by students about a general area of knowledge in order to enlarge their knowledge base or to resolve cognitive conflicts (Jirout & Klahr, 2011; Van der Meij, 1994). SIS questions express the genuine interest and intrinsic motivation of students to inquire into a topic (Graesser & Wisher, 2001). This review does not research academic help-seeking questions that request clarification or assistance from their teacher or peers with the aim of resolving problems related to completing academic tasks (Karabenick & Newman, 2006), or text-based questions which focus on the characteristics of text materials, such as the meaning of words, an analysis of grammatical constructions, or the reproduction of text statements, produced on the demand of the teacher (Scardamalia & Bereiter, 1992).

Student questioning is expected to have multiple educational benefits for both learning and teaching. First, student questioning is claimed to foster intrinsic motivation, for it allows students to set their own learning purposes (Gillespie, 1990; Scardamalia & Bereiter, 1992), which increases the motivation to pursue inquiries (Abrandt-Dahlberg & Öberg, 2001; Wells, 2001). According to the Social Determination Theory of Ryan and Deci (2000) intrinsic motivation for learning will increase, if students are allowed more autonomy and are supported in their perceived competence. Student questioning allows both autonomy, by acknowledging the personal need for seeking understanding, and the development of competence, by letting students pursue inquiries of their own interest. Second, student questioning is claimed to support knowledge construction because asking questions is a vital part of information seeking, and requires a conscious effort by the learner to identify cognitive conflicts or knowledge gaps in his or her prior knowledge (Farmer, 2007; Graesser & McMahen, 1993; Pardo & Bakes, 2015; Ram, 1991). Finally, student questioning is considered to be an effective metacognitive strategy which helps learners to monitor and self-evaluate their level of understanding (Scardamalia, 2002; Veenman, 2004), and can support forms of higher level thinking such as analyzing, reasoning, and hypothesizing (Graesser, Baggett, & Williams, 1996). Moreover, student questioning has been found to be a basic heuristic for young children to seek knowledge about the world (Chouinard, Harris, & Maratsos, 2007).

Besides the benefits student questioning seems to have for constructivist learning, research shows that it can support teaching in several ways. Teachers have been found to use student questioning to: (a) diagnose students' level of understanding, (b) evaluate their students' level of thinking, (c) enhance inquiry, and (d) evoke critical reflection (see for an extensive review Chin & Osborne, 2008). Therefore, student questioning is considered to be a potential resource for teaching students to practice self-regulated learning and acquire knowledge about the world.

However, although teachers generally acknowledge the benefits of student questioning for teaching and learning, research shows that teachers make little use of the potential of student questioning (Eshach, Dor-Ziderman, & Yefromsky, 2014). Several reasons might be the cause for this. First, teachers are concerned with meeting the demands of formal school curricula (Wells, 2001). Student questioning might disrupt or cause deviations from the smooth deliverance of well-planned lessons (Rop, 2002). Second, teachers often use questions in order to exercise classroom control (Reinsvold & Cochran, 2012). When teachers perceive student questions as a threat to this authority and control, they are inclined to reduce student questioning to a minimum (Chin & Osborne, 2008). Third, while many teachers hold the belief that they ought to know all the answers, few teachers are prepared to put their knowledge to the test through student questioning (Woodward, 1992; Zeegers, 2002). Finally, even if teachers would be willing and self-confident enough to support student questioning, most of them have not had sufficient training in pedagogical repertoires to guide student questioning (Lin, Hong, & Cheng, 2011).

Facing these challenges, teachers seem to need support that would enable them to guide *effective* student questioning, defined as aligning student questioning to the requirements of the curriculum, which consist of a set of predetermined learning goals established by the school system, syllabi, and/or the teacher. Although many studies pay attention to how teachers can elicit and train student questioning (Chin & Osborne, 2008), it remains unclear how teachers can align student questioning with curricular goals. What seems to be needed is a comprehensive overview of how teachers can guide effective student questioning. This literature review aims to identify emergent themes put forward by empirical research on teacher guidance of effective student questioning in primary school classrooms. First, we will examine the trends in the literature about student questioning and the process of questioning in more detail in order to determine inclusion criteria and develop a framework of analysis for this review.

2.2 THEORETICAL FRAMEWORK

In the literature two types of studies on student questioning can be distinguished. Most dominant in number are studies that focus on teaching students how to question, based on schema theory, activity theory, or metacognitive theory (Janssen, 2002). Distinctive features of this "*teaching to question*" approach are various methods of question-training, specific materials (such as question-starters and question-stems), and procedures for eliciting specific types of questions by students (for an extensive review see Rosenshine, Meister, & Chapman, 1996). Another type of study on student questioning, which emerged in the 1990s, focuses on how students can learn from their own questioning. This "*questioning to learn*" approach, mostly inspired by the Self Determination Theory and sociolinguistic perspectives on questioning, is aimed at developing an inquisitive stance and emphasizes the personal meaning and ownership of student questioning (Carlsen, 1991; Ryan & Deci, 2000). In this approach teachers support classroom dialogue about the process of inquiry and relate student questioning to students' prior experiences, current understanding, and personal interests (Kock, Taconis, Bolhuis, & Gravemeijer, 2015). The main difference between these approaches seems to be, that the "teaching how to question" approach focuses on developing questioning as a skill, while the "questioning to learn" approach aims at developing questioning as a stance.

Most studies in the "teaching how to question" approach seem to be grounded on the assumption that asking a question is a speech act, in which a student tries to convey a sense of curiosity through an utterance. The meaning of the question is then in the intention of the student and the recognition of the hearer of this intention (Henderson & Brown, 1997). From this perspective, teachers who are trying to develop student questioning have to support students in extending their vocabulary and improving their syntax in order to be able to convey their intentions most accurately. Therefore, many of these studies focus on the training aspect, by offering question-stems or question-heuristics to teach students how to formulate their speech act. However, students' original sense of curiosity is hardly ever explored and might even be ignored in this process, potentially leading to mechanically produced questions without personal meaning (Neber, 2008).

By contrast, in the "questioning to learn" approach student questioning is considered to be a stance, an epistemic attitude that involves perceiving the world from the perspective of wonderment or perplexity (e.g. Cochran-Smith & Lytle, 2009). This wonderment might initially be diffuse and difficult to put into words, but can gradually become more clear and focused when explored and discussed. If teachers perceive the task of guiding student questioning to be first and foremost about exploring and discussing students' sense of wonderment, asking questions is not a technical exercise, but a journey to develop both the focus and the adequate language to frame students' sense of curiosity. Although studies from the "teaching to question" approach have advanced our knowledge on question generation and formulation, this review focuses on the "questioning to learn" approach, in order to find out how teachers can guide intrinsically motivated student questioning in a way that meets curricular demands.

In order to analyze teachers' guidance of student questioning it is important to examine the process of questioning. In general, questioning can be described as a process that consists of three phases: (a) *generating,* (b) *formulating,* (c) *answering* questions (cf. Van der Meij, 1994; Ram, 1991. In the generating phase the learner becomes aware of the need or possibility to ask a question, triggered internally by a cognitive disequilibrium or externally by events or phenomena evoking a state of perplexity or an inquisitive stance. In the formulating phase, the learner tries to verbalize his or her perplexity by formulating a question (verbal coding) and can choose to express it in a social setting (social editing). In the third phase of answering, the learner consults available resources and processes acquired information in order to construct an answer to his or her question.

In practice, the process of questioning is often more dynamic and iterative than this linear model of generating, formulating, and answering questions might suggest. Generating and formulating questions can become an intertwined process (e.g. Wells, 2001). Finding preliminary answers might lead to reformulating questions, for instance (Van der Meij & Dillon, 1994). Initial questions, especially, might need reformulation when students become more aware of their emergent interests and learn to articulate their intentions (Tan & Seah, 2011). Student questioning can become progressive, for as students learn more about a domain they can raise better and more detailed questions (Ram, 1991). The ultimate goal in guiding student questioning is, arguably, that students get involved in a continuous and cyclic process of questioning in which new-found answers are the stepping-stones to new questions. This continuing process of generating, formulating and answering questions is referred to as progressive inquiry (e.g. Hakkarainen, 2003).

For the sake of reviewing teacher guidance with respect to student questioning, we use the three main phases of questioning to identify patterns in and among each phase of questioning. The model allows us to analyze and compare teacher guidance in various educational contexts within and between the three phases. The aim is to look for patterns that help teachers to start and maintain an almost continuous process of questioning and answering. Therefore, the underlying assumption is that in order to make student questioning effective, all phases should contribute to meeting curricular goals. But what challenges does this set for teaching?

In the phase of generating questions, the challenge for teachers is to make students aware of the possibility to raise intrinsically motivated questions about curriculum topics. First, teachers would like students to generate authentic SIS questions, based upon students' interests. However, it is not clear how teachers can help students to develop an interest in curriculum topics, which at first glance might not be connected to students' prior experiences and knowledge. Even when succeeding in raising interest, how can teachers prompt student perplexity and promote an inquisitive stance that leads to student questioning with respect to topics in the curriculum? Second, having operationalized question generation as the process of identifying what needs to be learned, teachers need to consider how they can provide a context in which students become aware of what is yet unknown to them (Ram, 1991). However, what teacher guidance can make students aware of what they do not know about the curriculum? Although some scholars suggest only a very limited amount of prior knowledge is necessary for students to raise questions (Chouinard et al., 2007), other scholars emphasize that some exploration of the topic is a prerequisite for generating adequate questions

(Markman, 1979; Van der Meij, 1994). Finally, the third challenge in this phase is to motivate students to consider raising their questions, when they have become aware of what needs to be learned. Dillon (1988) and Reinsvold and Cochran (2012) found that primary school students generally raise very few questions in class, while Graessar and Person (1994) reported that students in tutor settings tend to ask many more questions. Therefore, teachers need to find ways to create classroom environments in which students are more inclined to ask questions.

In the second phase of questioning, the challenge for teachers seems to be to support students in articulating their interests and sense of perplexity into investigable questions that address both the width and depth of the curriculum. Multiple studies show that many of students' initial questions seem to be both unfocused and uninvestigable (e.g. Biddulph, 1989; Chin & Kayalvizhi, 2002). It seems to be difficult for primary students to phrase questions which focus on their interests and which facilitate feasible investigations, partly due to developing vocabulary and literacy skills (Zeegers, 2002). Therefore, teachers have to find methods to guide students' initial questions so that they take on an investigable form without losing the students' original intent. A second challenge in the formulating phase is to guide student questioning so as to explore the width and depth of the curriculum. Coverage of the width of the curriculum seems to be challenged by the divergent interests of students, due to personal preferences and the general popularity of certain topics. This diversity in questioning might easily lead to partial knowledge construction for the individual student, and fragmented overviews of (sub-)domains on the collective level of the classroom curriculum (Baram-Tsabari, Sethi, Bry, & Yarden, 2006). Attaining more in-depth knowledge is another challenge, for students are not just expected to learn factual knowledge; rather, they are supposed to develop conceptual thinking in which they relate concepts with prior knowledge and different concepts to each other (Graesser & Wisher, 2001). However, unguided student questioning is seldom connected to prior knowledge and seems to be predominantly factual rather than conceptual (De Vries, Van der Meij, & Lazonder, 2008). Therefore, spontaneous student questioning might not meet the requirements for deep learning in terms of conceptual understanding. Key issues for teachers in the formulating phase are therefore to support students in articulating investigable questions and to guide student questioning so that it addresses both the width and the depth of the curriculum.

In the answering phase, the challenge in guiding effective student questioning appears to be to help students find relevant answers, and organize an efficient method for the exchange of learning outcomes. Finding answers to their questions can be expected to be an important prerequisite for students to advance their knowledge and to learn the curriculum. However, the exchange of learning outcomes also seems necessary. Individual students will most likely not be able to learn the whole curriculum on the basis of their own questions and answers, and therefore need the questions and answers of their fellow students as well. Scardamalia (2002) suggests that answers to individual student questions could be used as building blocks for collective knowledge construction in a community of learners.

Furthermore, to develop more in-depth knowledge of the curriculum, not only learning outcomes should be exchanged, but students should also sustain the inquiry by building upon each other's questions and raising follow-up questions, which lead to a deeper conceptual understanding (Scardamalia, 2002). Collaboration in a community of learners seems to be a key issue in the answering phase, but it is not yet clear how teachers can guide collective knowledge construction and sustained inquiry in a way that will meet the demands of the curriculum.

To summarize, although a considerable number of studies have focused on student questioning, their findings have been fallen short when it comes to helping teachers to guide student questioning in a way that meets the demands of the formal school curriculum. Key issues for teachers seem to be: a) to promote students' interest in curriculum topics and prompt students to experience a feeling of perplexity about these topics, b) to support students in articulating investigable questions and to guide student questioning so as to address the width and depth of the curriculum, and c) to support a collective inquiry that contributes to effective student questioning.

Important reviews in the literature on student questioning focused on issues such as its potential with respect to teaching and learning science – on teaching question generation strategies, on the role of student questioning in reading comprehension, literature, and prose-processing, and on the role of student questioning in the information-seeking process (Biddulph, Symington, & Osborne, 1986; Chin & Osborne, 2008; Cornbleth, 1975; Farmer, 2007; Gillespie, 1990; Graesser & Wisher, 2001; Janssen, 2002; Pedrosa-de-Jesus & Watts, 2012; Rosenshine et al., 1996; Woodward, 1992; Wong 1985). These reviews have, however, not yet examined how teachers can address the key issues with respect to guiding effective student questioning. To identify emergent themes concerning how to successfully implement effective student questioning in classroom practice, a qualitative description of patterns in teacher guidance is needed. For this purpose, the following research question is raised in this systematic qualitative literature review: Which emergent themes with respect to guiding effective student questioning in primary school classrooms can be derived from the literature?

2.3 METHOD OF REVIEW

2.3.1 Identification of Studies

A data set of articles was collected in three steps. First, we conducted an explorative computer search. To identify studies on student questioning in primary education, a computer-based search was conducted in the following databases: EBSCO, Google Scholar, JSTOR, Picarta, and ERIC. In the search query we used combinations of the following terms: student* AND question* AND (guid* OR generat* OR pos* OR ask* OR self-generat* OR self-formulat* OR develop*). In order to augment this search query, fragments of the titles of retrieved articles on student questioning were used as search terms in Google Scholar, which identified citing articles. To reduce the possibility of missing data, references from collected studies and review articles were scanned for relevant publications. In total, 385 possibly relevant studies were collected in this first round.

In the second step, abstracts of all retrievable studies were screened for eligibility criteria for both study and report characteristics. The criteria for study characteristics were: students as questioners, not teachers' questioning; SIS questioning, not academic help-seeking; knowledge-based questioning, not text-based questioning; reporting on teacher guidance or on characteristics of the learning environment that support teachers in guiding student questioning. Report characteristics were: peer-reviewed manuscripts published in scholarly journals and dissertations, published from about 1990, and containing empiric data collected in primary education. Of the 323 retrievable studies, 248 studies were identified as reports on student questioning. These studies were scanned to check if they matched all the eligibility criteria, resulting in a final dataset of 36 studies.

2.3.2 Analysis

The analysis was conducted in two steps. First an analysis framework and an analysis procedure were developed. The analysis framework initially only consisted of the three phases of questioning. To test the analysis framework, two researchers independently analyzed ten studies from the dataset and the outcomes were subsequently compared and discussed. From this preliminary analysis it became clear that the studies reported on teachers' guidance from three perspectives: a) teacher characteristics such as confidence, stance and attitude; b) teachers' instructional moves to support student questioning; and c) teachers' organization of collaboration and support. To improve the focus of our analysis, the three perspectives on teacher guidance were integrated into our analysis framework, resulting in a three by three matrix to summarize findings from each study. Then, an analysis procedure was developed to document systematically for each study, general bibliographical and methodological categories (cf. Cooper, 1998), as well as the findings concerning teacher guidance structured according to the analysis framework. All findings were stored in an Access™ database.

In the second step, *summary reports* were extracted from the database, and subsequently analyzed to identify characteristics of teacher guidance within the analysis framework. Every time a new characteristic was identified, an appropriate label was created. For each label a table was made, to register in what studies which relevant findings had been identified. By labelling all findings from the summary reports both quantitatively and qualitatively, trends, similarities, differences, and peculiarities of teacher guidance of effective student became apparent between studies, which allowed the identification of emergent themes for teacher guidance of effective student questioning.

To minimize risk of bias when analyzing and interpreting, the strength of evidence in each study was estimated (Table 2.1). For each study it was established if it was either a single, multiple case, or (quasi-)experimental study. To describe the context of the studies, the focus of studies, the number and grade of participants, the type and duration of the intervention, the type of instruction, the type of student inquiry, and the connections to larger research or intervention programs were recorded. The independence of the research was estimated by identifying the role of teachers as actors or as (co-)researchers. Neither of these categories are indicative of the quality of the studies per se, but together they help to put the findings in perspective with respect to the strength of the evidence. Statistical evidence in the studies was rare and of various nature; hence, no meta-analysis could be conducted.

2.4 FINDINGS FROM REVIEWED STUDIES

As Table 2.1 shows, the dataset consists of 12 single case studies, 19 multiple case studies, and 5 (quasi-)experimental studies. In 18 studies the researchers were independent and did not participate in the teaching, in 8 studies teachers reported on their own teaching, and 10 studies were conducted by mixed teams of teachers and researchers. The studies address (sometimes multiple) school subjects such as biology (9 studies), literacy (5 studies), numeracy (4 studies), physics (13 studies), and (social) sciences (9 studies). About two-thirds of the studies were conducted in Canada (5) and the USA (18), although studies were also included from countries as diverse as Australia (4), Brazil (1), Ghana (1), Hong Kong (1), New Zealand (2), Russia (1), Singapore (2), Taiwan (2), and the United Kingdom (1). The age of the student participants varied between 4 to 13 years old. Most studies (24) report on older primary students (grades 4–6 or even 7), but 14 studies report on younger students (grades 1–3). The types of intervention varied both in form and in duration, ranging from regular lessons to project-based units, and lasting from one lesson to multiple years. Teacher guidance of student questioning was predominantly done in a face-to-face setting, although in 10 studies the instruction was also supported by an Electronic Learning Environments (ELO). Students used various strategies to investigate their questions such as: conducting experiments (14 studies); observing the natural environment (2 studies); consulting secondary sources, such as expository texts, experts, the internet, or ELOs (16 studies); discussing literary texts (3 studies) and solving mathematical problems (4 studies).

The next sections present a qualitative synthesis of the findings from the reviewed studies structured according to the analysis framework. First, the influence of teacher characteristics on student questioning is reported. Second, various instructional moves by teachers to support questioning are explored. Third, the (impact of) organization of collaboration is described.

Table 2.1. Overview Study Characteristics

Study	Type of study	Researcher	Subject	Focus of study	Student participants	Grade	Country	Intervention	Duration	Instruc-tion	Student inquiry	Reported outcomes
Aguiar et al. (2009)	Multiple case	Teacher	Physics	Types of dialogue	3 classrooms N = ?	7–9	Brazil	Regular lessons	11 lessons	Face-to-face	Conducting experiments	Type of question-pattern of interaction
Allmond and Makar (2010)	Quasi-experi-mental	Teacher	Numeracy	Developing investigable questions	N = 66	3	Australia	Unit on *creating questions*	8 lessons 1 month	Face-to-face	Solving math-problems	Level of questions (investigative)
Awanta (2013)	Multiple case	Independent	Numeracy	Knowledge construction in classroom discourse	N = 48	7	Ghana	Regular lessons	7 weeks	Face-to-face	Solving math-problems	Nature of questions (basic- critical)
Baumfield and Mroz (2002)	Multiple case	Independent	Critical literacy	Type of discourse which fosters student questioning in community of inquiry	2 classrooms N = ?	2–5	UK	Community of inquiry on narrative texts	29 sessions	Face-to-face	Questioning narrative texts	Question categories Influence text type Benefits to pupils and teachers
Beck (1998)	Single case	Independent	Social science	Teacher's stance on student questioning	1 classroom N = ?	4	USA	A *Project – Approach* Science unit	4 weeks	Face-to-face	Consulting internet, experts, expository texts	Type of questions (focus on learning potential)
Biddulph (1989)	Multiple case	Independent	Physics	'Interactive' teaching approach based on student questioning	4 classrooms N = ?	1–5	New Zealand	Unit structured by *Interactive approach*	12 lessons	Face-to-face	Conducting experiments	Teachers' & Students' responses to teaching approach
Biddulph (1995)	Multiple case	Independent	Numeracy	Questions about number	N = 276	5–6	New Zealand	Student teachers' assignment	4–5 sessions	Face-to-face	Solving math-problems	Nature of questions (various categories)
Brown and Campione (1994)	Quasi-Experi-mental	Independent	Biology	Knowledge building in community of learners	not reported	2–6	USA	Project –Based Science units	1 semester (example)	Face-to-face	Consulting internet, experts, expository texts	Knowledge Test Depth of analogy Types of explanations

Study	Type of study	Researcher	Subject	Focus of study	Student participants	Grade	Country	Intervention	Duration	Instruc-tion	Student inquiry	Reported outcomes
Busching and Slesinger (1995)	Multiple case	Mixed	Social Science & Critical Literacy	Learning environment to raise 'real' questions	5 classrooms (N= 125)	7	USA	Unit on WO2	5 lessons (50 min)	Face-to-face	Discussing literary and expository texts	Nature of questions (focus on function)
Chin and Kayalvizhi (2002)	Single case	Mixed	Science	Questions for open science investi-gations	N = 39	6	Singapore	I: invited to ask questions II: modelling questions	I: 8 weeks II: 3 x 1 hour	Face-to-face	Consulting internet, experts, expository texts	Topics of interest Typology of investigable questions
Chouinard et al. (2007)	Experi-mental	Independent	Biology	Information Requesting Mechanism	N = 67	K–1	USA	I: Walking the Zoo II: Problem-solving task	I: 1 session II: 1 session	Face-to-face	Observing real objects, toys and images	I: Impact stimulus on questioning II: effect questions on problem-solving
Commeyras (1995)	Single case	Mixed	Critical literacy	Encourage student – centered questions	N = 20	2	USA	7th lesson in series of 18	1 lesson	Face-to-face	Discussing literary texts	Intention & meaning of questions
Diaz Jr. (2011)	Multiple case	Independent	Physics/ Biology	Student-centered questioning & argumen-tation	3 classrooms N = 60-75?	5	USA	Units structured by *Science Writing Heuristc*	3 semesters	Face-to-face	Conducting experiments	Level of questions (Bloom) Level of argumentation
Di Teodoro et al. (2011)	Multiple case	Teacher	Numeracy	Integration of meaningful mathematical questions in teaching	4 classrooms N = ?	2–3	Canada	Lessons on three literature- based mathematical problems	Several lessons in the course of a year (?)	Face-to-face	Solving math-problems	Levels of questions Teacher's self-report
Hakkarainen (2003)	Single case	Independent	Biology	Progressive Inquiry in computer supported classroom	N = 28	5–6	Canada	*Computer Supported Intentional Learning Environment*	1 academic year	Face-to-face & online	Consulting internet, ELO, expository texts	Level of explanations Level of student questions
Harris et al. (2011)	Multiple case	Independent	Biology	Classroom discourse to elicit and develop students' questions	3 teachers	5	USA	Unit on Isopods	12 weeks	Face-to-face & online	Consulting internet, experts, expository texts	Student assessment? Instructional moves

Study	Type of study	Researcher	Subject	Focus of study	Student participants	Grade	Country	Intervention	Duration	Instruc-tion	Student inquiry	Reported outcomes
Hume (2001)	Single case	Teacher	Physics	Developing knowledge-building Community	N = 24	6–7	USA	Unit on Light and Colour	4 weeks	Face-to-face	Conducting experiments Informational texts	Classroom interaction Development of Questions Student engagement
Hung et al. (2014)	Single case	Independent	Biology	Developing student questioning ability in field inquiry	N= 43	5–6	Taiwan	Unit on Ecology of Wetlands- including 3 fieldtrips	4 months	Face-to-face & online	Observing wetlands Consulting ELO, internet & expository texts by mobile device	Autonomous questioning Assistance to others questioning Autonomous question correcting Assistance to others question correcting
Keys (1998)	Multiple case	Mixed	Physics	Generative model of teaching science (Harlen & Osborne, 1985)	2 classrooms N = ?	6	USA	Investigative units	3 x 4 weeks (= 3 x 15 hours)	Face-to-face	Conducting experiments	Reasoning strategies for question generation Teacher's roles
Lai and Law (2013)	Multiple case	Independent	Social science	Questioning and quality of knowledge construction	N = 86	6/10	Hong Kong	Knowledge Forum (CSILE)	6 x 3 x 50 min 6 weeks	Face-to-face & online	Consulting ELO, internet, experts, expository texts	Level of questions Levels of explanations
Lehrer et al. (2000)	Multiple case	Mixed	Biology	Design tools for fostering inquiry	1 classroom N = ?	1/3–5	USA	Units on *decomposition & plant growth*	1 year	Face-to-face	Conducting experiments	Development of inquiry
Lin et al. (2009)	Quasi-experi-mental	Independent	Physics	Change of classroom learning environment by inquiry-based activities and student questioning	N = 92	5	Taiwan	Inquiry activities in Science Lessons	4 hours each week During 1 year	Face-to-face	Conducting experiments	Inquiry activities questioning skills What Is Happening In the Classroom? (WIHIC) test

Study	Type of study	Researcher	Subject	Focus of study	Student participants	Grade	Country	Intervention	Duration	Instruc-tion	Student inquiry	Reported outcomes
MacKenzie (2001)	Single case	Independent	Science	Effect of teacher's stance on learning community	N = 125	7	USA	Mind Games in science lessons: Inquiry activities on hypothetical situations	1 year	Face-to-face	Consulting internet, experts, expository texts	Description of classroom activities and discourse
Martinello (1998)	Single case	Mixed	Social science	Co-inquire with children cognitive apprenticeship	N = 10	2/5/7	USA	Summer group	3 hours for 10 weeks	Face-to-face	Consulting internet, experts, expository texts	Description of student questions & inquiry activities
Ness (2014)	Single case	Mixed	Literacy	Addressing students' (disregarded) spontaneous questioning	1 classroom N = ?	3	USA	Student centered small group sessions to address questions	Twice a week for several(?) weeks	Face-to-face	Consulting expository texts	Description of student questions & inquiry activities Answers
Penuel et al. (2004)	Multiple case	Mixed	Science	design of a socio-technical system to support enhanced student questioning	2 teachers in design phase 75 teachers in test phase	5	USA	Using handheld computers and Boomerang software in various subjects in science education	Several sessions	Face-to-face & online	Not reported	Teacher and student use and experience
Scardamalia and Bereiter (1992)	Quasi-Experi-mental	Independent	Biology/ Science	Educational potential of student's questions	2 classrooms N = 50	5–6	Canada	Units of inquiry in CSILE and informal question-generating sessions	1 session	Face-to-face & online	Not reported	Educational value of questions Student rating of questions
Simpson (1996)	Single case	Teacher	Literacy	Developing critical literacy by student questioning	1 classroom N = ?	6/7	Australia	Reading circles	Not reported	Face-to-face	Discussing literary texts	Student questions Teacher's role
Tan and Seah (2011)	Multiple case	Independent	Biology	Questioning behaviour of students engaging in inquiry science using Knowledge Forum	N = 138	4	Singapore	Knowledge Forum (CSILE)	April-October	Face-to-face & online	Consulting ELO, internet, expository texts	Types of questions (Ideational functions) Nature of inquiry task

Study	Type of study	Researcher	Subject	Focus of study	Student participants	Grade	Country	Intervention	Duration	Instruc-tion	Student inquiry	Reported outcomes
Van Tassel (2001)	Single case	Teacher	Physics	Knowledge building by student questioning in science	N = 20	1–2	USA	Unit of solids, liquids and gasses	2 semesters	Face-to-face	Conducting experiments	Transcripts of discourse, student's questions & teacher's considerations
Van Zee et al. (2001)	Multiple case	Mixed	Physics	Types of science conversation that encourage student questioning	5 classrooms	1–6	USA	Guided discussions, student generated inquiry & peer collaboration on science topics	Many months(?)	Face-to-face	Conducting experiments	Factors that stimulate student questioning in science conversation
Virgin (2015)	Case study	Teacher	Social Science	Big Ideas as focus for instruction and teaching with and for student questioning	Not reported	6–7	USA	Not reported	3 year	Face-to-face & online	Consulting internet, expository texts	Procedures to elicit student questioning & connect student questioning to curriculum
Weizman et al. (2008)	Case study	Teacher	Chemistry & Physics	Functionality of Driving Question Board for organizing and focusing student questioning	Two examples for classrooms	7	USA	Project –Based Science units	Not reported	Face-to-face	Conducting experiments	Sample Driving Board Questions Sample interview responses
Zeegers (2002)	Multiple case	Independent	Physics	Praxis of primary teachers who encouraged student questioning in science	3 classrooms	4–7	Australia	Project –Based Science units Some cases *cooperative learning*	5–8 weeks	Face-to-face	Conducting experiments	Teaching strategies Teacher's views Factors for generating & using questions
Zhang et al. (2007)	Multiple case	Independent	Physics	Online science discourse aimed at knowledge building	N = 22	4	Canada	Knowledge Forum (CSILE)	4 months	Face-to-face & online	Conducting experiments Consulting ELO, internet, expository texts	Inquiry threads Idea improvement Knowledge gains (individual & collective)

Study	Type of study	Researcher	Subject	Focus of study	Student participants	Grade	Country	Intervention	Duration	Instruc-tion	Student inquiry	Reported outcomes
Zhang et al. (2009)	Multiple case	Independent	Physics	Effect of various forms of student collaboration on knowledge building	N = 22	4	Canada	Knowledge Forum (CSILE)	3 years	Face-to-face & online	Conducting experiments Consulting internet, expository texts	Awareness of contributions, complementary contributions, distributed engagement.
Zuckerman et al. (1998)	Multiple case	Mixed	Physics	Science curriculum build on student inquiry	N = 120	1–4	Russia	Davydov styled curricula for science and math	Twice a week 3 years	Face-to-face	Conducting experiments	Descriptions of inquiry activities, Tests of symbolic representations

2.4.1 Teacher characteristics.

Twelve studies have shown that teacher characteristics such as self-confidence and positive attitude support an inviting and accepting classroom atmosphere, in which students feel free to raise questions without fear of losing face (Aguiar, Mortimer, & Scott, 2009; Baumfield & Mroz, 2002; Beck, 1998; Biddulph, 1989, 1995; Hume, 2001; Lehrer, Carpenter, Schlaube, & Putz, 2000; MacKenzie, 2001; Van Zee, Iwasyk, Kurose, Simpson, & Wild, 2001; Zhang, Scardamalia, Lamon, Messina, & Reeve, 2007; Zeegers, 2002). Teacher confidence has been found to pave the way for letting go of too much control over the process of questioning (Biddulph, 1989; Van Tassel, 2001; Zuckerman, Chudinova, & Khavkin, 1998). When feeling confident, teachers are able to allow for unexpected and unclear student questioning. Van Zee et al. (2001) found that confident teachers are willing and able to cope with unexpected and potentially threatening student questions. Hume (2001) observed, that her confidence in students' agency and her willingness to empower students helped her to let students struggle to make sense of what they are thinking. Keys (1998) found that teachers' confidence was reflected in their decision to allow grade 6 students to explore inappropriate lines of inquiry, with the aim of letting students experience the true nature of scientific investigation, rather than providing the students with correct procedures, that are not fully understood. Both Diaz Jr. (2011) and Zeegers (2002) have shown that teachers' level of confidence in student questioning seems more related to the level of domain knowledge than to teaching experience. For instance, both authors found a significant correlation between the level of a teacher's conceptual domain knowledge and the amount of student questioning in classroom discussions. Furthermore, Zeegers points out that, in addition to domain knowledge, a thorough understanding of scientific procedures contributes to a teacher's confidence.

Nine studies reported that a positive stance of the teacher supports student questioning. Seven studies found that when teachers acknowledge and appreciate all student questions, students become more willing to raise questions. For instance, Beck (1998) describes a fourth-grade teacher who explicitly acknowledges the potential for learning of each of her students' questions, even when the questions appear naïve or unclear. This teacher succeeds in establishing a classroom culture in which asking and discussing questions is the norm. Similarly, Zeegers (2002) observed a teacher who focused on the articulation of wonderment, deliberately disregarding the phrasing or practicality of initial student questions, which resulted in greater student confidence with respect to raising questions. Also, Simpson (1996) found that when grade 6 students are encouraged to write down all questions, even those who seem to be trivial, students feel more at ease raising their questions. Brown and Campione (1994) and Van Tassel (2001) note that when teachers value student questions as serious attempts to construct knowledge, this stance positively influences students' willingness to ask questions. Two studies have explicitly shown that teachers need to set specific norms in order to establish a supportive classroom culture. MacKenzie (2001) observed a teacher who first ensured that all her grade 7 students knew her strict norms about mutual respect, before engaging in student questioning. Hume (2001) reported that she instructed her grade 7 students to allow for multiple perspectives, when emotional responses fuelled classroom discussion on questions about the assumed causal relationship between eye-colour and sight.

Based on the data, the following general picture emerges about the effects of teachers' confidence, stance, and attitude on effective student questioning. The review's findings suggest that confident teachers, having extensive content and procedural knowledge, can create a positive classroom culture for student questioning by valuing all student questions and by modelling their own questioning behaviour.

2.4.2 Teacher's Instructional Moves

All the studies in the dataset show that teachers use a variety of instructional moves (Table 2.2) – which in this study is defined as a teacher's actions meant to guide student questioning by means of speech and activities (cf. Harris, Phillips, & Penuel, 2011). Instructional moves vary between the provision of opportunities for exploration and discussion to strategies to prompt and develop questions, and from the organization of inquiries and exchanges of findings to support for student to reflect on their sense of perplexity, their questions and their findings. This section reports on how teachers use instructional moves to guide the generation, formulation, and answering of student questions.

Guiding question generation.

Eight case studies suggest that teachers need to provide students with the time and opportunity to become acquainted with the relevant topic. Biddulph (1995) observes that children in grades 5–6 find it difficult to raise questions about mathematics unless they have some idea of the concept under consideration. Biddulph (1989) also reports that students need adequate time initially to explore phenomena and events before generating scientific questions. A similar observation was made by Martinello (1998), who notes that students' real interests only surface in the third or fourth week of co-inquiry, even when they are allowed to choose a topic of their own interest. Hume (2001) found that when grade 7 students explore a scientific topic for a longer period of time, their sense of puzzlement deepens. Similarly, Busching and Slesinger (1995) report that grade 7 students explain that it is hard to ask questions about a social science subject when just starting reading about it, because "You [aren't] in to it yet" (p. 346). And Lehrer et al. (2000) show that grade 1 and students in grades 3–5 generate more and more interesting questions when they can build upon their knowledge and experience

Table 2.2. Findings on Teacher's Instructional Moves

		Generating questions				Formulating questions					Answering questions		
		Prompt perplexity				Divergent phase		Convergent phase			Guide knowledge construction		
Study	Grades	Prior knowledge	Literature	Exploratory activity	Question or task	Share	Write	Clarify	Categorize	Model	Individual	Collective	Progressive
Aguiar et al. (2009)	7–9	X	-	X	-	X	-	-	-	-	-	-	-
Allmond and Makar (2010)	3	-	-	X	-	X	X	X	X	-	-	-	-
Awanta (2013)	7	-	-	-	X	X	X	-	-	-	-	-	-
Baumfield and Mroz (2002)	2–5	-	X	-	-	X	X	X	X	X	-	-	-
Beck (1998)	4	X	-	-	X	X	X	X	X	-	X	X	-
Biddulph (1989)	1–5	-	-	X	-	X	X	X	-	X	X	-	-
Biddulph (1995)	5–6	-	-	-	-	X	-	-	-	-	-	-	-
Brown and Campione (1994)	2–6	-	X	-	-	X	X	X	X	-	X	X	-
Busching and Slesinger (1995)	7	-	X	-	X	X	-	X		X	-	-	X
Chin and Kayalvizhi (2002)	6	-	-	-	X	X	X	X	-	X	-	-	-
Chouinard et al. (2007)	K–1	-	-	X	-	-	-	-	-	-	-	-	X
Commeyras (1995)	2	-	X	-	X	X	-	X	-	-	-	-	-
Diaz Jr. (2011)	5	-	-	-	-	X	X	-	-	-	-	-	-
Di Teodoro et al. (2011)	2–3	-	X	-	X	X	X	-	X	-	-	X	-
Hakkarainen (2003)	5–6	-	-	-	X	X	X	X	-	-	X	X	X
Harris et al. (2011)	5	-	-	-	X	X	X	X	-	X	X	X	-
Hume (2001)	6–7	-	-	X	-	X	X	X	-	-	-	X	X
Hung et al. (2014)	5–6	-	-	X	-	X	X	X	X	-	X	X	-

		Generating questions				Formulating questions					Answering questions		
		Prompt perplexity				Divergent phase		Convergent phase			Guide knowledge construction		
Study	Grades	Prior knowledge	Literature	Exploratory activity	Question or task	Share	Write	Clarify	Categorize	Model	Individual	Collective	Progressive
Keys (1998)	6	-	-	X	-	X	X	X	-	-	X	-	-
Lai and Law (2013)	6/10	-	-	-	X	X	X	-	-	-	-	-	-
Lehrer et al. (2000)	1/3–5	X	-	X	-	X	X	X	X	X	X	X	X
Lin et al. (2009)	5	-	-	X	-	X	X	-	-	-	-	X	-
MacKenzie (2001)	7	-	-	-	X	X	-	-	-	-	-	-	-
Martinello (1998)	2/5/7	-	-	-	X	X	X	X	-	X	X	-	X
Ness (2014)	3	-	-	-	-	X	X	-	-	-	X	-	-
Penuel et al. (2004)	5	-	-	-	X	X	X	-	X	-	-	-	-
Scardamalia and Bereiter (1992)	5–6	-	-	-	X	X	X	-	-	-	-	-	-
Simpson (1996)	6/7	-	X	-	X	X	X	X	-	-	-	-	-
Tan and Seah (2011)	4	-	-	-	X	X	X	-	-	-	X	X	-
Van Tassel (2001)	1–2	X	-	X	-	X	X	X	X	-	X	X	X
Van Zee et al. (2001)	1-6	-	-	-	X	X	X	X	-	-	-	-	X
Virgin (2015)	6-7	-	-	-	X	X	X	-	-	-	-	X	-
Weizman et al. (2008)	7	-	-	-	X	X	X	-	X	-	-	X	-
Zeegers (2002)	4–7	-	-	X	-	X	X	X	X		X	X	X
Zhang et al. (2007)	4	-	-	-	X	X	X	X	-	-	-	X	-
Zhang et al. (2009)	4	-	-	-	X	X	X	X	-	-	-	X	-
Zuckerman, et al. (1998)	1–4	-	-	X	-	X	X	X	-	-	X	-	-
Total		4	6	13	21	35	30	22	11	7	14	16	9

about the natural phenomenon under investigation. Van Tassel (2001) observes that student questions were more valuable and had taken on personal meaning after the initial exposure to the topic. However, a remarkably contrasting finding was identified by Scardamalia and Bereiter (1992). They report that when teachers instruct grades 5–6 students to explore prior knowledge and reference materials to raise questions, students predominantly ask "basic information" questions aimed at fact-seeking. In an experimental condition in which students were invited to ask questions spontaneously, without exploring their prior knowledge first, students asked significantly more educationally valuable "wonderment questions", seeking relations and explanations. As a possible explanation, it is suggested that when teachers explicitly avoid the suggestion that questions need to be investigated, students feel more free to articulate their real wonderments and do not select beforehand which questions might be easy to answer.

All studies, except Ness (2014) and Diaz Jr. (2011), report that teachers use prompting strategies to elicit interest from students and stir a sense of perplexity about the topic. Four types of prompting strategies used by teachers become apparent from the dataset: activate prior knowledge, explore literature, organize exploratory hands-on activities, and present questions or problem-solving tasks.

First, four studies show that teachers prompt questioning by activating students prior knowledge about the relevant topic. Lehrer et al. (2000) found that a teacher began a science-unit with an extended conversation about what grade 1 students already knew about the topic. Van Tassel (2001) describes how she activates her grade 1 and grade 2 students' prior knowledge by asking them to explain their personal understanding of an issue to each other in small-group discussions. She reports that these discussions make the students both aware of their prior knowledge and of gaps in their knowledge. Beck (1998) shows that a teacher can make grade 4 students aware of their background knowledge about the government by asking students to discuss their own experiences in making difficult choices and decisions. Aguiar, Mortimer, and Scott, (2009) report that in grade 7, student questioning tends to emerge when teachers link the topic to student interests and experiences – for example, by providing examples that have had high exposure in the media.

A second strategy teachers use to prompt student questioning, found in five studies, is to explore and discuss literature. Baumfield and Mroz (2002) found that teachers can evoke spontaneous student questioning in grades 2–5 when they choose texts with an intriguing twist or puzzle in them. Busching and Slesinger (1995) observe that students with limited prior knowledge can be prompted by a storybook about the experiences of a young girl in World War 2. Brown and Campione (1994) report that both an informational text and a play can serve as starting points for a biology unit on endangered species in grades 5–6. Simpson (1996) shows that teachers easily engage students in raising questions about picture books when these student questions are used to guide other groups in discussing the books. Commeyras (1995) found that discussing the biography of Harriet Tubman elicits lively discussions and questions about the lives of slaves among students in grade 2. Di Teodoro et al. (2011) report how storybooks can be used to introduce and discuss mathematical problems in grades 1–2.

A third teacher strategy for eliciting perplexity was found in 13 studies and reports on how teachers organize exploratory (hands-on) activities in which students can observe, collect, and compare data. Keys (1998) reports that teacher-led science experiments aroused both interest and curiosity in grade 6 students. Aguiar et al. (2009), Biddulph (1989), Hume (2001), Lin, Hong, and Chen (2009), Van Tassel (2001), and Zeegers (2002) show that both younger and older primary students, are prompted not only to explore but also to raise questions about effects and explanations by various hands-on science experiments using and testing materials. Collecting and comparing data from the real world, either during field-trips in the wetlands in grades 5–6 (Hung et al., 2014), or by observing changing patterns in rain-fall on the roof of the class in grade 6 (Keys, 1998), or observing differences in rates of decomposition between tomatoes and pumpkins in grades 1–2 (Lehrer et al., 2000), or by visiting the Zoo (Chouinard et al. 2007), prompted student questioning about natural phenomena. Comparing maps of islands to explore patterns of erosion has also been reported to be an effective strategy for evoking wonderment and curiosity (Zuckerman et al., 1998). Hume (2001) reports that exploratory activities by the whole class supports a shared understanding of the topic, introduces a common language for discussing the topic, and raises students' interests.

Finally, 11 studies point to the use of various types of questions or problem-solving tasks as a prompting strategy. The most basic application of this strategy is simply to invite students to share their wonderments – as reported by Awanta (2013), Beck (1998), Busching and Slesinger (1995), Harris et al. (2011), Martinello (1998), Scardamalia and Bereiter (1992), Simpson (1996), and Van Zee et al. (2001) – by asking questions such as "What would you most like to know about…?"; "Is there anything you would like to find out about…?". Hakkarainen (2003) found that a simple prompt: "I need to understand" to be the most effective scaffold for student questioning in an online discussion forum called "Computer Supported Intentional Learning System" (CSILE). More complex teacher questioning techniques are also reported to be effective for prompting student questioning. MacKenzie (2001) shows that a teacher's imaginative questions, such as "What if the sun becomes a supernova?"(p. 146), can elicit student wonderment. Weizman, Shwartz, and Fortus (2008) found teachers who prompted their students with "driving questions", that is, open-ended questions in everyday language that contextualized physics content to students' personal interests, such as, for example "When can I believe my eyes?"(p. 35). Lai and Law (2013), Tan and Seah (2011), and Zhang et al. (2007, 2009) note that inquiries on Knowledge Forum, an online discussion forum, starts with "seed-questions" such as "Can technology solve the problem of global warming?". Virgin (2015) describes how he prompts student questioning on the historical period of Reconstruction in the US by using statements such as: "The Civil War didn't change much"(p. 99). Tan and Seah (2011) found that the type of task set by a teacher on Knowledge Forum influences the types of student questions that are elicited. They find that a fact-seeking task predominantly generates fact-seeking questions, while a problem-solving task generates the greatest number and greatest variety of questions.

Having prompted students' perplexity in various ways, three studies suggest that teachers should also support students in reflecting on their perplexity from a curriculum perspective. Keys (1998) notes that when teachers ask students to explain relations between prompted observations to the scientific topic, students seem to be able to relate their own personal experiences to the exploration of science ideas. Similarly, Van Tassel (2001) reports helping students to relate their observations to their prior knowledge and experiences by asking them to formulate preliminary explanations. Zuckerman et al. (1998) found that teachers help students to find patterns in their observations by making graphical representations of the main features and characteristics of the phenomenon under study.

Next, with respect to helping students reflect on their sense of perplexity, eight studies show how teachers connect student interest to key concepts in the curriculum. Diaz Jr. (2011), Virgin (2015, Zhang et al. (2007, 2009), and Zuckerman et al. (1998) report that teachers use key concepts or Big Ideas, which capture the most essential characteristics of the subject under study, to connect student questions to curricular goals. Beck (1998) shows an example of how a teacher was able to raise the interest in the key concept of "government" by relating this concept to students' previous experiences with making choices and decisions. Brown and Campione (1994) found that a skilled teacher appropriates the spontaneous interest of the students for endangered species and encourages students to consider underlying key concepts such as metabolic states, survival and reproduction. Zhang et al. (2007, 2009) report about a teacher who organizes "rise-above" discussions with students to reflect on their developing understanding of the key concepts under study. Virgin (2015 presents narrative evidence that when teachers generate a conceptual focus, student questions go deeper with respect to, for example, a key concept such as "change" in American History. In order to be able to do this, Baumfield and Mroz (2002) observe that teachers need in-depth knowledge of both the curriculum content and students' interests and prior knowledge.

Guiding question formulation.

Whereas in the generating phase teachers' guidance is aimed at raising wonderment and exploring a topic, in the formulating phase teachers' guidance aims at helping students actually formulate and pose their questions. In total, 35 studies show that teachers first guide the student question formulation process through a divergent phase by organizing opportunities for students to articulate and share their questions (Table 2.2). Teachers organize various forms of classroom discussions in order for students to become aware of the range of questions they have formulated and share ideas. However, explicit planning for question formulation might sometimes be necessary, as found by

Zeegers (2002), who observes that a teacher needs to allocate time for questions during scientific hands-on experiments because students are so immersed in the task that they forget to think about their questions.

In 31 studies teachers requested that students record their questions (Table 2.2), either on paper or digitally in e-learning environments, such as Boomerang, CSILE, Knowledge Forum, and Ubiquitous Problem Based Learning System (UPBLS). Hume (2001) explains why she, as a teacher, asks her students to write down questions: A written question is asynchronously available, accessible for everyone to read and to react to, and therefore affords more involvement from students and more opportunities for further examination and reflection. However, not all teachers choose to record questions immediately. Van Zee et al. (2001) report that a grades 1–2 teacher first allows students to discuss their wonderings and questions and waits to record questions, because this might disturb spontaneity and emergence of other student questions.

Contrasting findings have been reported on the quality of the students' initial questions. As regards to coverage of the curriculum, Biddulph (1989) and Beck (1998), found that the majority of initial student questions tend to be connected to curriculum content. Hakkarainen (2003) and Zhang et al. (2007) show that student questioning on Knowledge Forum covers all the required topics of the curriculum and even elaborates on some of the topics in the higher grades. Hakkarainen and Zhang et al. find student questions more exploratory than fact-seeking, which they interpret as students seeking a deep understanding and thorough explanations of the phenomena under study. However, other studies report initial student questions to be naïve (Biddulph, 1989; Chin & Kayalvizhi, 2002; Zeegers, 2002; Zuckerman et al., 1998), not investigable (Hume, 2001; Van Tassel, 2001), lacking in purpose (Allmond & Makar, 2010), and in general aimed at fact seeking rather than being exploratory in nature (Lai & Law, 2013; Martinello, 1998).

Twenty-five studies show that teachers organize a convergent phase once students have formulated their initial questions (Table 2.2). In this phase teachers help students to further develop their questions and prepare them to investigate the topic. Six studies discuss why teachers support the development of students' questions. Martinello (1998) shows that students from various grades (1–5) need teacher support before they can articulate what they want to discover and that their initial questions do not reflect their true interests. Similarly, Allmond and Makar (2010) found that grade 3 students are not always able to frame their questions to their intent, because they are still developing their language and literacy skills. Beck (1998) shows how a teacher needs to explore together with grade 4 students "the question within the question" to find what is really meant or sought after, thus clarifying the meaning and intention of questions. However, Busching and Slesinger (1995) and Commeyras (1995) suggest that teachers should be aware of their own prejudices when interpreting the intent of a student's question. Teachers should be especially sensitive to the fact that their understanding of the meaning of a question might not match the student's intent, according to Commeyras. Simpson (1996) notes similarly that teacher concerns about following the curriculum might restrain teachers in recognizing what the students are wondering about.

Four teacher strategies for developing questions have been identified: clarifying questions, categorizing questions, developing criteria for questions, and modelling questions. The most reported teacher strategy is to clarify the meaning, intent, and assumptions imbedded in students' questions (22 studies, Table 2.2). This support seems to require teachers that are good listeners and who can also ask students regarding what is not being communicated. Besides carefully listening, teachers can take various instructional actions to clarify the questions. Hakkarainen (2003), Harris et al. (2011), Hume, (2001), Lehrer et al. (2000), Van Zee et al. (2001), Zeegers (2002), and Zhang (2007, 2009) report that teachers can simply ask students to clarify what they mean. Hume (2001) and Biddulph (1989) found that teachers also discuss the assumptions underlying the questions with their students. Martinello (1998) and Keys (1998) observed teachers guiding their students to consciously explore their topic from different perspectives, thus helping students to identify factors most salient to the investigation. Biddulph (1989) and Harris et al. (2011) report that asking students to suggest possible answers makes them aware of the underlying intent and assumptions of their questions. However, Van Tassel (2001) emphasizes that teachers should be prepared that to interpret the meaning of questions is not a clear-cut and straightforward process, but " …involves lot of messing around with ideas and fumbling for words and clarity" (p. 53).

A second teacher strategy for developing student's questioning capabilities, found in 11 studies (Table 2.2), is to make the students aware of the quality of questions by categorizing them. Lehrer et al. (2000) report that teachers help students in grades 3–5 evaluate their questions by writing them on index cards and asking students to arrange and rearrange them into categories. In the subsequent classroom discussion, the values and consequences of different types of questions are explored. Similarly, Allmond and Makar (2010) observe teachers that instruct grade 3 students to sort their own questions for investigability and subsequently ask them to justify their choices. Van Tassel (2001) reports that her grade 2 students categorize their questions in groups before selecting ones to inquire into. Weizman et al. (2008) find that a teacher instructs grade 7 students to categorize their questions in order to connect them to the key concepts and to become aware of the variety in the type and level of questions. Hung et al. (2014) and Penuel, Yarnall, Koch, & Roschelle (2004) report, that teachers instruct their students to categorize their own questions using a generic rubric for question quality as a reference.

Four studies show a third strategy used to support student questioning in which teachers develop and discuss quality criteria for questions together with students. Zuckerman et al. (1998) found teachers that involve all students in discussing the investigability of initial naïve questions and thus help students to reformulate questions along lines that can be investigated. Both Allmond and Makar (2010) and Lehrer et al.

(2000) observed how teachers help their students to develop criteria for good questions by discussing aspects such as the interest in expected outcomes, to what extent the questions are researchable, and considerations of evidence. Di Teodoro et al. (2011) report that a team of teachers for grades 1–2 initially set out to derive the criteria for "deeper" versus "superficial" questioning themselves by sorting out student questions. However, the teachers realized this was also a valuable learning experience for their students and decided to involve them in discussing the question criteria. Di Teodoro et al. found this strategy to be highly supportive of students and note that the percentage of "deeper" student questions rose from 16 to 70% in the cases they investigated.

A fourth strategy for teachers to develop student questioning is modelling, as reported in six studies (Table 2.2). Some teachers provide students with example questions. Busching and Slesinger (1995) show how a teacher shares her own questions to support student questioning. Other teachers model the vocabulary and syntax of questioning. Lehrer et al. (2000) report how a teacher models modes of conversation for discussing the quality of questions. Allmond and Makar (2010) report how a teacher models the syntax of statistical questions by exploring and discussing the effects of ambiguous words on subsequent inquiry. Zeegers (2002) observes teachers who model types of questions that are investigable by emphasizing scientific vocabulary such as *effect, compare, explain, evidence*. Martinello (1998) found that teachers support question development by modelling the syntax of "I wonder" questions. Finally, there are teachers who model their own thinking to conceptually elevate student questions. For instance, Harris et al. (2011) report that the teachers who were most successful in developing student questioning use re-voicing and think-aloud strategies as ways to explain and clarify their own understanding and to engage students in refining their own questions.

Although in many studies teachers apply strategies to develop questions, three studies emphasize that teachers should also be aware that the quality of student questioning is not dependent on its form, but rather on its function within the context. Both Busching and Slesinger (1995) and Di Teodoro et al. (2011) find that some questions, which appear to be "on the surface", actually stimulate deeper thinking. They also observe that "surface" questions often lay the factual foundation for creating deeper questions. Simpson (1996) reports that all students' questions, regardless of type or quality, elicit interested responses from fellow students and lead to educationally valuable classroom discussions. Simpson concludes that the development of understanding seems not to be dependent on the quality of the question but on the discussion that follows.

Guiding answering questions.

Twenty-four studies in the dataset (Table 2.2) report on teacher guidance in the answering phase, although in all cases this is originally not the focus of study. The evidence is therefore mostly indirect and no effects have been reported. Teacher guidance in the answering phase addresses two main issues: a) to guide students' questions to an answer, and b) to exchange learning outcomes in order to develop a collective understanding among the students.

In the process of guiding students to answer their questions, teachers provide several forms of practical support. First, teachers support students in finding the most appropriate method of inquiry. Lehrer et al. (2000) reports that teachers discuss with students in grades 3–5 which tasks and tools the questions call for, taking the prior knowledge of the students into account. Van Tassel (2001) describes how she asks her grade 2 students how to proceed in order to get answers. The students tend to suggest various authoritative resources, such as books, experts, and the internet, but never come up with the idea of constructing knowledge themselves by conducting experiments until prompted by the teacher. Harris et al. (2011) observed that teachers prepare grade 5 students for investigation by asking them procedural questions concerning planning and conducting experiments.

Second, teachers support students in locating the relevant resources. Both Beck (1998) and Tan and Seah (2011) report that teachers need to support grade 4 students in identifying relevant information on the internet, because students tend to include interesting but irrelevant information. Furthermore, teachers can provide support by offering appropriate resources to their students. Ness (2014) found that a teacher was able to get grade 3 students answer their "parking lot questions" by matching them with appropriate informational texts. Busching and Slesinger (1995) offer their grade 7 students a variety of expository and literary texts as starters for their inquiries. Beck (1998), Brown and Campione (1994) and Martinello (1998) organized things so that their grade 1–6 students could consult external experts by inviting them as guest speakers or by contacting them by email or phone.

Third, teachers help students to design or conduct experiments and help to organize and visualize data and findings. Van Tassel (2001) reports how she models the skills of observing, recording, discussing, and reflecting on experiments for her grade 2 students. Zuckerman et al. (1998) observed how teachers model experiments that investigate erosion using trays of sand, clay, water, and wind. Likewise, Keys (1998) found how teachers help students to test ideas by discussing how to set up experiments with insulating materials. Even when having conducted experiments, teacher guidance might still be needed, as reported by Lehrer et al. (2000) and Martinello (1998), who have found that teachers need to help students to organize the data they have collected.

Teachers have also been observed offering students conceptual support. Teachers can probe students' understanding by asking clarification, elaboration, or justification questions, as reported by Keys (1998) and Zhang et al. (2007). Lehrer et al. (2000) observed that teachers help students in grades 1–2 to deepen their understanding of answers by discussing and developing consensual criteria for what counts as convincing evidence. Hakkarainen (2003) found the teachers request that their grade 4 students explicate exploratory relations between biological phenomena in order to develop understanding of their findings. Teachers also bring in new ideas and prompts to consider deeper principles. Brown and Campione (1994) show how a teacher encourages students in grades 5–6 to consider deeper principles of metabolic rate, survival, and reproductive strategies when exploring the topic of endangered species. Zhang et al. (2009) found that a teacher can bring in important new ideas, emergent in Knowledge Forum, to a grade 4 student’s attention with the aim of deepening an inquiry. Virgin (2015) reports that teachers connect all grade 7 student questions to key historical concepts. By revisiting these key concepts in different historical periods, teachers help students acquire knowledge about these concepts across multiple contexts.

Having guided students to answer their questions, teachers face the challenge of guiding the process aimed at reaching a shared understanding among all the students. In 16 studies, which report about guiding the building of collective knowledge (Table 2.2), three types of instructional moves are identified: discussing knowledge advances, interconnecting findings, and exchanges of distributed expertise. In three studies teachers initiated a meta-discourse about knowledge advances. Hume (2001) facilitated metacognitive reflection on the knowledge building process during classroom discussion by asking students to summarize their findings in a “progress update”. Keys (1998) similarly observed that teachers reflect with their students on the progress of their findings. Zhang et al. (2009) report that the teacher they followed initiate discussions about “What are our knowledge advances” and collectively reviews the students’ input on Knowledge Forum.

Another instructional move for teachers to guide collective knowledge building is to interconnect questions and answers. Harris et al. (2011) show that during discussions teachers relate the findings of some students to those of others, highlighting the scientific ideas the answers may have in common. Similarly, Tan and Seah (2011) report that the teacher they followed helps students to rise above their own findings by summarizing their understanding of the topic, emphasizing differences and similarities, making patterns in various answers explicit and reasoning together to find coherent scientific explanations.

A third type of instructional move to guide collective knowledge construction is to organize exchanges of distributed expertise. Brown and Campione (1994), Hume (2001), and Van Tassel (2001) have found that through questioning, students can become experts in a subtopic. Beck (1998), Brown and Campione (1994), Lin et al. (2009), and Zeegers (2002) show that in many classrooms teachers ask their students to share their expertise with their classmates. Hakkarainen (2003), Hung et al. (2014), Tan and Seah (2011), Zhang et al. (2007. 2009) show that e-learning environments such as CSILE, Knowledge Forum, or UBPLS support students in continuously exchanging questions, ideas, and findings.

Eight studies suggest that questioning should not stop when students find their answers. In these studies, progressive inquiry was observed in which questions evolved gradually from fact-seeking to more exploratory meaning-seeking. Busching and

Slesinger (1998) report a gradual development of grade 7 student questioning from unfocused information-seeking questions about World War 2 to more focused exploratory questions, the latter not only aimed at understanding but also reflecting moral, psychological, and historical wonderment. Zeegers (2002) observed a forward spiralling process in which the investigation of students' questions seemed to lead to further questions and new investigations. Lehrer et al. (2000) and Van Tassel (2001) found that some of the most absorbing questions only arise in grades 2–5 as a by-product of inquiries into other questions. Martinello (1998) describes how the duration of involvement with a topic deepens questioning behaviour, and reports that over time more student questions emerge that explore anomalies and analogies, or that have an evaluative nature. Zuckerman et al. (1998) also report that when students find answers to their self-formulated questions, this frequently raises new questions, for the new information makes students aware of new problems and cognitive discrepancies. Chouinard et al. (2007) report that the order of questions of children seems to be similar to that of adults. Both first build a base of knowledge by asking descriptive questions and then gradually seek deeper or more causal information. Hakkarainen (2003) reports that the exchange of questions and answers between students in grades 5–6 in CSILE is identified by experts in the field as progressive inquiry, in which students improve their working theories on the functions of the human body. These findings suggest that guiding students to progressive inquiry seems to be beneficial for both developing questioning capabilities and deepening knowledge construction.

Teachers use various instructional moves to support progressive inquiry. Lehrer et al. (2000) show that teachers facilitate students in grades 1–2 and grade 3–5 to continuously revisit knowledge, questions, inscriptions, and data in order to take new and more challenging steps, sending the message that work conducted is not work completed. Martinello (1998) reports that teachers can support progressive inquiry by seeking questions rather than answers in the dialogue with the students. Hume (2001) and Zeegers (2002) describe how teachers organize students so that they share and challenge each other's findings, in order to support the idea that student investigations lead to further questions and new investigations. Hakkarainen (2003) reports that a teacher can facilitate progressive inquiry by suggesting new conceptual perspectives to students in grades 5–6. For example, when students are focusing on exploring the number of different brain cells the teacher suggests: "I was wondering if you were going to consider how the cells differ in functions?" (Hakkarainen, 2003, p. 1081). Furthermore, Hakkarainen (2003), Zhang et al. (2009), and Van Zee et al. (2001) found that teachers support progressive inquiry by highlighting newfound information and thereby bringing it to the attention of all students. These findings suggest, that when teachers make students aware that findings are just tentative conclusions, new questions and lines of inquiry can be evoked.

We conclude that teachers can use a wide variety of instructional moves to support student questioning in the three phases of questioning. Teachers can prompt relevant student questioning by various instructional moves, such as activating prior knowledge, exploring and discussing literature, hands-on experiments and questions, or problem-solving tasks. Some studies suggest teachers should not only raise student interest, but should also connect student's sense of perplexity to key concepts from the curriculum. After generating questions, teachers often organize convergent activities to record and develop student questioning. Teachers can guide students so that they reformulate their initial questions by clarifying their intentions and meaning, seeking and applying criteria for investigability, and modelling questioning behaviour. However, an important prerequisite for mediating questions seems to be that teachers recognize the potential in all student questions for learning the curriculum. Teacher guidance in the answering phase is aimed at the construction of both individual and collective knowledge. By giving both practical and conceptual support, such as finding the method of inquiry, locating resources, designing experiments, developing criteria for evidence, offering new perspectives, and explicating relations, teachers can guide students in a way that enables them to answer their individual questions. An awareness of the progressive nature of inquiry helps teachers to deepen inquiries and to realize a chain of inquiry in which student questioning evolves.

2.4.2 Organizing Peer Collaboration

Thirty-four studies show that teachers organize peer collaboration to enhance their instructional moves (Table 2.3). Several forms of peer collaboration with various aims have been identified in the data. Teachers organize whole and small group discussions aimed at opening perspectives, sharing ideas, exchanging and modelling questions, seeking and planning investigations, presenting findings, and reflecting together on the meaning of their findings. This section elaborates on the reported support and limitations of peer collaboration for guiding effective student questioning.

Peer collaboration is reported in 10 studies to support the generation of questions. Allmond and Makar (2010), Biddulph (1989), Baumfield and Mroz (2002), Chin and Kayalvizhi (2002), Hume (2001), Keys (1998), Lehrer et al. (2000), and Virgin (2015) all report that questions emerge more easily during small or whole group discussions. Biddulph (1989) observed how a few students can ignite student questioning in multiple classroom discussions in grades 1–5 and calls this pattern a "ripple-effect". Similarly, Zuckerman et al. (1998) report that when some grade 4 students take initiative to ask questions, other students gradually join in and elaborate upon these questions. Awanta (2013) also shows that when some grade 7 students share their critical questions this inspires their peers to join in and hypothesize, predict, seek, and generate questions for things that puzzle them. Allmond and Makar (2010) found that grade 3 students are initially reluctant to write questions individually, but when students work with a partner or in a small group they engage in substantive conversations about their questions.

Table 2.3. Findings on Peer Collaboration and Visual Tools

Study	Grades	Peer collaboration		Visual support		
		Whole class	Small group	Simple tools	Advanced tools	Complex tools
Aguiar, et al. (2009)	7–9	X	X	-	-	-
Allmond and Makar (2010)	3	X	X	-	-	-
Awanta (2013)	7	X	-	-	-	-
Baumfield and Mroz (2002)	2–5	X	X	-	-	-
Beck (1998)	4	X	X	X	-	
Biddulph (1989)	1–5	X	X	X	-	-
Biddulph (1995)	5–6	-	X	-	-	-
Brown and Campione (1994)	2–6	X	X	X	-	-
Busching and Slesinger (1995)	7	X	X	X	-	-
Chin and Kayalvizhi (2002)	6	-	X	-	-	-
Chouinard, et al. (2007)	K–1	-	-	-	-	-
Commeyras (1995)	2	X	-	-	-	-
Diaz Jr. (2011)	5	-	-	-	-	-
Di Teodoro, et al. (2011)	2–3	X	-	-	X	-
Hakkarainen (2003)	5 - 6	-	X	-	-	X
Harris, et al. (2011)	5	X	X	-	-	-
Hume (2001)	6–7	X	X	-	-	X
Hung, et al. (2014)	5–6	-	X	-	X	-
Keys (1998)	6	X	X	X	-	-
Lai and Law (2013)	6/10	X	X	-	-	X
Lehrer, et al. (2000)	1/3–5	X	X	-	X	-
Lin, et al. (2009)	5	-	X	-	-	-
MacKenzie (2001)	7	X	-	-	-	-
Martinello (1998)	2/5/7	-	X	-	X	-
Ness (2014)	3	-	X	X	-	-
Penuel, et al. (2004)	5	X	-	-	X	-
Scardamalia and Bereiter (1992)	5–6	-	-	-	-	-
Simpson (1996)	6/7	X	-	-	-	-
Tan and Seah (2011)	4	X	X	-	-	X
Van Tassel (2001)	1–2	X	X	X	-	-
Van Zee, et al. (2001)	1–6	X	X	X	-	-
Virgin (2015)	6–7	-	X	X	-	-
Weizman, et al. (2008)	7	X	X	-	X	-
Zeegers (2002)	4–7	X	X	-	-	-
Zhang, et al. (2007)	4	X	X	-	-	X
Zhang, et al. (2009)	4	X	X	-	-	X
Zuckerman, et al. (1998)	1–4	X	-	X	X	-
Total		26	27	10	7	6

Next, with respect to question generation, nine studies report how the process of question formulation is supported by peer collaboration. Lehrer et al. (2000) and Weizman et al. (2008) found that classroom discussions help students in grades 1–5 and grade 7 to become familiar with the range and variety of questions, as well as help to learn to consider additional ways of questioning. Busching and Slesinger (1995) report that grade 7 students benefit from discussing questions because students show each other examples of questions. Di Teodoro et al. (2011) and Lehrer et al. (2000) show that students in grades 1–2 students can build on each other's ideas when refining questions, especially when teacher models appropriate criteria for evaluating listed questions. Allmond and Makar (2010), Baumfield and Mroz (2002), Hakkarainen (2003) and Hung et al. (2014) report that students can give peer feedback on both the content and wording of each other's questions working in small groups. Baumfield and Mroz (2002) and Chin and Kayalvizhi (2002) found that discussing questions in small groups removes misunderstandings and tangential questions and leads to more precise questions.

Seven studies show that peer collaboration supports planning and conducting investigations. Beck (1998), Brown and Campione (1994), Keys (1998) and Zeegers (2002) found that teachers organize small independent research groups, in which students in grades 4–7 collaboratively plan and conduct investigations, and support each other in collecting and interpreting data. Similarly, Lehrer et al. (2000) and Van Tassel (2001) report that small groups of students in grades 1–2 choose their questions and subsequently collaboratively seek methods for investigation. Harris et al. (2011) found that students help each other determine steps for setting up experiments, and reason together through benefits and drawbacks of following particular steps. Busching and Slesinger (1995) report that students benefit from each other by sharing experiences and knowledge produced in subsequent inquiries.

Six studies show how teachers organize peer collaboration in order to exchange findings. Some teachers opt for exchanges involving the whole class. Di Teodoro et al. (2011) found that teachers organize Math Congresses for students to discuss questions and explore their findings. Lai and Law (2013) show that students report every first ten minutes of each lesson, on progress from each small group, showcasing their work and sharing important new findings or ideas. Zhang et al. (2009) found that a teacher can regularly review with students' work in progress on Knowledge Forum, where they can interact with each other, contributing questions and knowledge and ideas related to different subtopics. Other teachers alternate small group and whole class exchanges. Virgin (2015) reports that teachers group their students on the basis of similar or different questions, and hence organize an exchange of the findings. Brown and Campione (1994) report that students regroup regularly in reciprocal teaching seminars in which each student is an expert in one subtopic holding one-fifth of the information of the whole curriculum theme. Harris et al. (2011) report how a teacher alternates whole class and small group discussions for three consecutive rounds to compare a scientific definition of the concept "habitat" with students' own knowledge and ideas about this concept.

Eight studies found that peer discussions about questions or findings supports student reflection and argumentation. Van Tassel (2001) observed that grade 2 students learn to explicate their own views when discussing their questions in small groups. Allmond and Makar (2010), Biddulph (1989) and Lehrer et al. (2000) report that negotiating questions in small groups opens up new and different perspectives and supports students in learning to think critically and purposefully. Van Zee et al. (2001) show that reflection is prompted when students compare and discuss their findings. Beck (1998) observes that a full airing of the various theories forces students to think through their ideas and provides both an interest in the question and a context for an answer. Harris et al. (2011) and MacKenzie (2001) found that an exchange of findings is most supportive when teachers encourage students to articulate to their peers constructive criticisms, suggestions, questions, or approval. Another strategy to prompt reflection and argumentation, reported by Harris et al., is asking students to predict their answers and invite their peers to ask clarification questions about predictions and justify why a prediction should be considered true or false.

Seven studies report on some of the limitations of peer collaboration for guiding student questioning. Three studies suggest teachers need to take group dynamics into account when organizing peer collaboration. Zeegers (2002) reports that grade 7 students, who are not accustomed to exchanging ideas in classroom discussions, might be reluctant to share their questions with the whole class. Similarly, Simpson (1996) reports grade 6 students feel more safe sharing ideas and questions in small groups first, rather than directly in discussions involving the whole class. Another potential drawback of peer collaboration has been reported by Baumfield and Mroz (2002), who found that students tend to select the questions for which a consensus can most easily be found and that more complex questions are often dismissed.

Another limitation of peer collaboration is that teachers experience guiding small group work as demanding. Keys (1998) reports that even with three professionals in the classroom, guiding several small groups in their scientific investigations is a considerable challenge. Zeegers (2002) and Beck (1998) both observed that guiding student questioning puts a heavy demand on a teacher's time and capacities. Moreover, Zhang et al. (2009) found that students who work on Knowledge Forum in fixed small groups are very dependent on the teacher's organizational and communicative skills in building collective knowledge.

To overcome these drawbacks, several studies suggest flexible grouping. Four studies show how teachers organize flexible forms of peer collaboration by making students collectively responsible for generating, formulating, and answering their questions. Brown and Campione (1994) describe how teachers support the development of a community of learners by, on the one hand, allowing students in grades 5–6 to develop individual expertise by researching subtopics, and, on the other hand, by organizing regular small group meetings in which students exchange their expertise about these subtopics with their peers. In this community, teachers hold all students responsible for the mastery of the whole theme, not just for their subtopic. Hume (2001) reports, that she explicitly makes students responsible for both researching questions and exchanging answers. She invites students to take responsibility for all questions they are interested in, and encourages them to exchange questions, ideas, and findings. As a result, most students sign up for several questions – often different questions than the ones they generated themselves – and students collaborate in several investigations in various groupings. Hume observes that students show a collective willingness to contribute to knowledge construction because of this shared responsibility. Zhang et al. (2007, 2009) similarly show that inviting students to contribute to all lines of inquiry results in opportunistic flexible grouping. This means that students group and regroup depending on their interests and emergent needs. This form of opportunistic peer support seems to make students feel responsible for each other's work. This responsibility is, for instance, reflected in one student's proposal that all questions have to be "approved" by the rest of the class in order to ensure their contributions to common goals, before investigations can proceed. Zhang et al. (2009) found that flexible grouping is more effective than fixed small groups with respect to the degree of participation in each other's questions, the spread of knowledge to class members, the coherence of network structures, and the extent of student independence from teacher support. Similarly, Harris et al. (2011) found that teachers who are the most successful, in terms of student knowledge gains in assessments, organize things so that there is a shared responsibility for advancing collective knowledge among their students.

However, a shared conceptual focus might be a necessary prerequisite before teachers can make students collectively responsible for their questioning. Although Biddulph (1989) reports that diversity in student questioning accommodates students of different ability, and Tan and Seah (2011) found that a variety of questioning makes it possible to explore a curriculum topic from multiple perspectives, Zeegers (2002) observed that varied levels of conceptual understanding also might obstruct peer collaboration. Zeegers found in multiple classrooms that when students do not have a common shared basic understanding of the topic, they find it hard to support each other in generating, formulating, and answering questions. It might therefore be no coincidence that Brown and Campione (1994) and Hume (2001) first establish a common language and understanding in the classroom community by organizing exploratory activities and classroom discussions. Moreover, Zhang et al. (2009) report that a "central view", a key concept central to the curriculum topic, supports opportunistic collaboration, because it gives a shared purpose and direction to collective student inquiry.

In summary, organizing peer-collaboration can support the guidance of student questioning and has been found to have positive effects on all three phases of questioning. The retrieved studies suggest that the most successful teachers support collective knowledge construction by discussing knowledge advances, interconnecting findings, and organizing exchanges of distributed expertise. Although peer-collaboration can support effective student questioning, teachers need to create a safe classroom environment for students in which questioning is the norm. A potential risk in peer collaboration is that working in small fixed groups might lead to students retaining their dependency on the teacher's assistance. In contrast, there is evidence that organizing things so that students have a shared responsibility for collective knowledge advances, while having a shared conceptual focus, seems highly effective for guiding student questioning.

2.4.3 Organizing visual support

To further support collective responsibility, many studies mention the use of visual tools. In 23 studies, teachers organized forms of visual support to guide student questioning (Table 2.3). When comparing their function for guiding student questioning, three types of visual tools emerge. Simple visual tools have mainly the function to support the sharing of questions and/or findings. More advanced visual tools do not only support sharing questions and/or findings, but are also used to organize and refine questions or transform findings into graphical representations. The most complex visual tools have multiple functions, in addition to sharing, organizing and refining questions and sharing and transforming findings, they also provide a flexible structure for elaborating knowledge construction, allowing for emergent questioning and lines of inquiry, as well as for organizing peer support and feedback.

Ten studies show that teachers use simple visual tools to guide student questioning (Table 2.3). In six studies teachers used simple visual tools to support the exchange of questions. Van Zee et al. (2001) found that a teacher requests that her grade 1 students record their questions with the aim to remember, to share, and to compare them and possibly to try to find some answers. Zuckerman et al. (1998) describe how students in grades 3–4 record upcoming questions during inquiries on a poster called "Our unresolved Questions" in order to share them with the class and to remember them for later. Brown and Campione (1994) report that students in grade 5–6 write their questions on post-its and place them on a bulletin board. By categorizing their questions students are able to identify relevant subtopics for further investigation. Busching and Slesinger (1995) observed that a chart of student questions on the classroom wall tends to grow over time, depicting the development in student questions. Before starting their final inquiry projects, students select the most important questions in a classroom discussion from this chart. Biddulph (1989) found that when teachers obtain and record students' questions in public, a stimulus is given to other students to consider aspects that they may not have thought of yet. Van Tassel (2001) describes how teachers brainstorm with grade 2 students about the topic "Air" and organize their questions on a poster. When exploring the topic further by conducting classroom experiments, student observations are again recorded on a chart, with the aim of visualizing these new understandings. However, although teachers seek to make students understand the relation between their observations and the principles of air, these relations are not visualized. The findings suggest that simple visual tools might help students to remember, share, and compare their questions.

Four studies report how teachers use simple visual tools to support the exchange of findings. Beck (1998) describes how grade 4 students, as experts in their subtopic, are required to create a piece of writing, something artistic, and a diagram to share their findings with the whole group. Keys (1998) also observed how grade 6 student groups make colourful posters to summarize the investigations that they present to the class. In both cases, the effects of these tools on the distribution of knowledge were not reported. Virgin (2015) reports that facilitating online environments such as Google Drive or Schoolology are used to support grade 7 students and get them to interact with each other and the teachers when investigating Big Ideas in History. Information on perceived support, however, was not reported. Ness (2014) found that grade 3 students eagerly research their own questions that are posted on a “Parking Lot” poster, because they cannot be addressed during class. When students identify some of the answers, they suggest that their findings should be placed on a “Free Way” poster. Simple visual tools are used for exchange of findings, but it is unclear to what extent they contribute to building collective student knowledge.

The use of advanced visual tools has been reported in 10 studies (Table 2.3). Four studies show how teachers use them for the development and refinement of student questions. Di Teodoro et al. (2011) observed how students in grades 1–2 place their questions on a T-chart, which is a graphic organizer on which students list and examine two facets of a topic, to distinguish between “surface” and “deeper” questions. By discussing with students the T-chart, teachers identify criteria for “deeper” and “surface” questions. Teachers visualize these criteria on a poster called “Diving deep for treasure”, showing the analogy of an anchored ship, which helps both teachers and students to more easily identify the goals of questioning. The pre- and post-comparison of questions shows that students ask significantly more “deeper” questions. Hung et al. (2014) report on the “Ubiquitous Problem Based Learning System” (UPBLS) a software application for handheld devices. Hung et al. show that UPBLS can be used for collecting, sharing, and refining students’ questions during and after field trips, but UPBLS also provides an online discussion forum, an e-library, and tools for collecting environmental data. Students work in small groups and improve their own questions and those of their peers by giving peer feedback in UBPLS, using scoring rubrics for questioning ability as reference. Tests show, that both novice grade 5 and experienced grade 6 students improve their questioning abilities significantly. Penuel et al. (2004) describe “Boomerang”, an software application for handheld devices by which students can share their questions by beaming them to peer devices or to the teacher’s computer. Boomerang can also be used to categorize questions by using a generic question rubric. The students’ motivation to use the application is reported to be high, but the effects on questioning ability have not been reported. Weizman et al. (2008) describe the use of a "Driving Question Board" (DQB) in a grade 7 science class, a large poster board that presents the central "driving" question and is surrounded by sub-questions which address the various sub-topics of the unit. At the start of unit, the DQB was jointly constructed in a classroom discussion, and the teacher's driving- and sub-questions were, in turn, surrounded by student questions. During lessons teachers can use DQB for various purposes, such as scaffolding practice of question-asking by categorizing, refining or deleting questions, connecting activities to the driving question, relating student questions to specific content topics, and sharing and organizing the findings. Both students and teachers report, that the DQB has supported them in keeping a conceptual focus and connecting findings and activities to the questions.

Three studies show how teachers can use advanced visual tools to organize and transform student findings. Martinello (1998) observed how teachers introduce students to different types of graphic organizers and ways of visually displaying data, such as time-lines, charts, diagrams, graphs, and Venn diagrams. These graphics help students in grades 2–7 to find meaningful patterns in their data and answers to their questions. Guided viewing of the graphics supports students and helps them to find their next questions, as the guided viewing makes them aware of gaps in their knowledge. Lehrer et al. (2000) show that the teacher encourages students in grades 1–2 to move "beyond observation toward inscription" (p. 83). Students use graphical representations to record, describe, and analyze their data, in forms such as strips of paper representing the length of a stem in order to compare the growth of plants. A discussion of these graphical representations and other types of data displays, such as charts, tables, and Venn-diagrams, inspires students to engage with many of the most interesting questions because they become aware of the emerging properties of the phenomenon under study. Zuckerman et al. (1998) also report about teachers helping students to design their own visual representations or models of the phenomenon being studied. By discussing differences and similarities between these representations, teachers guide students and help them identify important features or properties which can be further investigated in experiments. Advanced visual tools seem to support teachers when they seek to improve the quality of questions, to organize exchange of questions and findings, to challenge students about their thinking, and to raise new questions.

Six studies report on complex visual tools (Table 2.3). In five out of these six studies, teachers use either "Knowledge Forum" (KF) or its predecessor "Computer Supported Intentional Learning Environment" (CSILE) (Hakkarainen, 2003; Lai & Law, 2013; Tan & Seah, 2011; Zhang et al., 2007, 2009). KF and CSILE are electronic learning environments consisting of a communal database in which students can share their questions, theories, and findings as "notes". These notes are digital objects which are accessible for everyone to give comments in response to, ask for clarification, or suggest refinements, but which can only be altered by the author. All five studies report that students in grades 4–6 students can record and share new resources and discoveries in KF/CSILE and sustain the online discourse in order to advance community understanding.

Besides offering a platform for sharing questions and findings, KF and CSILE also provide an adaptable structure for emergent ideas and developments. Zhang et al. (2007, 2009) show that the teacher can initiate the unit in KF with one central “view” about “Light” in which grade 4 students record their questions and theories. In the third week, when students realize that this single view becomes too “messy”, students propose creating more views about focal themes such as shadows, colours, reflections, to accommodate the various emergent lines of inquiry. Then all the notes are reorganized in the new views and the views are mutually hyperlinked for easy navigation in KF. When students make further progress in their investigations, they start to realize that each inquiry involves various sub-issues. To represent the evolving goals, students create subsections within each view. Zhang et al. found that KF supports elaborate and flexible knowledge construction and is adaptable to new emergent questions and ideas.

KF and CSILE are also reported to support students’ sense of collective responsibility. Hakkarainen (2003) shows that peer and teacher feedback on student notes in CSILE allows students in grades 5–6 students to refine their questions and develop progressive inquiries. Zhang et al. (2007, 2009) found that KF allows for opportunistic collaboration in which all students are free to explore any problem from any view in the database. Working with views in KF helps to align all student contributions to the central conceptual focus and makes the structure of the collaboration fluid. Because students do not work in fixed groups connected to one subtopic, but in small groups that form and reform based on evolving needs, students have been reported to take responsibility for the overall growth of the database.

Hume (2001) describes another complex visual tool: the “Knowledge Wall (KW)”. The KW is a 22 feet long chalkboard in the classroom on which her grade 7 students can post questions, theories, and answers written on sticky-notes. Students are free to join any line of inquiry and many students are active in several investigations. Hume observes that students not only share findings, they also challenge each other’s questions and answers by posting peer feedback and thereby deepening the inquiry. Students have been reported to show a strong sense of collective responsibility for the KW, which becomes apparent when Hume suggests making a summary of the notes. This proposal is met with fierce resistance from students until the teacher clarifies that it is not her intention to end the inquiry but only to give a “progress update”. Although the KW is reportedly useful for organizing the exchange and development of student questioning, keeping track of responses to earlier input and the availability of space for contributions are found to be issues that become problematic as the inquiry progresses.

In summary, teachers used visual tools to support student questioning in 50% of the studies. The visual tools used varied both in functionality and in form. While simple representations can be used for guiding the generation and formulation of questions and the exchange of answers, more advanced and complex tools also support reflection on the process of questioning and make possible the construction of collective knowledge. The visual tools also vary between traditional forms of graphical representations, such as posters, charts, and diagrams, and digitally enhanced visual tools, such as ELOs and mobile apps. Although all visual tools are reported to support teacher guidance of student questioning to some extent, complex visual tools have been found to allow for more student autonomy and to support teachers in realizing progressive inquiries.

2.5 DISCUSSION

Previous research has shown that student questioning has potential for teaching and learning in primary education, but teachers seem to find it difficult to implement effective student questioning in their classrooms (e.g. Biddulph, 1989; Rop 2002; Wells, 2001; Zeegers, 2002). Effective student questioning was defined as the alignment of student questioning to the requirements of the curriculum. Although a substantial number of studies on student questioning were retrieved, we were not able to find a systematic review of teacher guidance with respect to effective student questioning. The aim of this review, therefore, was to derive emergent themes that come out of the empirical research on teacher guidance of effective student questioning in primary classrooms. The following central research question was addressed: Which emergent themes for guiding effective student questioning in primary classrooms can be derived from the literature?

To analyze the retrieved studies, a three-step model of generating, formulating, and answering student questions was used, as well as three perspectives on teacher guidance: teacher characteristics, teachers' instructional moves, and organizing support by peer collaboration. In the theoretical framework, several challenges for guiding effective student questioning were identified in each phase of questioning. In the generating phase the challenges seemed to be to promote students' interest in curriculum topics, to prompt students to feel a sense of perplexity about these topics and to enhance their inquisitive stance. In the formulating phase teachers were challenged to support students in articulating investigable questions and to guide student questioning to address the width and depth of the curriculum. Finally, in the answering phase, teachers faced the challenge of supporting the construction of collective knowledge and evoking progressive inquiries that contribute to effective student questioning.

From this review it can be concluded that four emergent themes in teacher guidance contribute to addressing these challenges. First, effective student questioning requires confident teachers, who create a supportive classroom culture for question generation and acknowledge the potential in students' initial questions. The focus in teacher guidance should be on supporting students' inquisitive stance. When teachers establish a safe and welcoming classroom environment for raising initial questions, students seem to gradually develop the skill to formulate their interests into authentic investigable questions. By taking into account the dynamic nature of questioning and regarding the initial questions as steps in the curriculum, some teachers and students succeed in making inquiries progressive. Then, the dynamic nature of questioning arises in all its strengths, because the process of questioning and answering becomes truly cyclical. Second, providing a conceptual focus supports students and helps them raise relevant but also authentic questions about the topic at hand. Such a conceptual focus could be a *core curriculum*, a curriculum consisting of a limited number of key-concepts which represent the major ideas and perspectives on the topic. A core curriculum allows both the freedom for divergent questioning that addresses the width of the curriculum and the structure to develop questioning that gets at the depth of the curriculum. A conceptual focus also makes it possible for answers to converge into a kind of collective building of knowledge. Third, teachers and students should be encouraged to take collective responsibility for the effectiveness of student questioning. Peer collaboration helps teachers and students to generate a diversity of questions, to value the potential of questions, to support discussion and mediation, and to assume a collective responsibility that fosters progressive inquiry. Fourth, visualizing the questioning process helps in guiding all phases of student questioning. Teachers can use visual tools to help students become aware of their prior knowledge and interests. Visual tools can also support students in organizing their newfound knowledge and making them aware of new questions. By visualizing the cyclical process of questioning and answering it becomes possible to create a collective workspace in which students and teachers can discuss and record progressive inquiry. Hence, in answer to our research question, four emergent themes for guiding effective student questioning in primary classrooms have been identified: (a) acknowledge the potential in all questions, (b) define the conceptual focus in the core curriculum, (c) organize collective responsibility, and (d) visualize progressive inquiry.

To correctly interpret our conclusions, we would like to point out some of the assumptions that guided the choices with respect to methodology. This review aimed to identify emergent themes in the literature that might support teachers in guiding effective student questioning in inquiry-oriented classrooms in primary education. Although the goals of the review might be considered aggregative, setting out to determine "what works for teachers", its methodology is mainly configurative, identifying patterns in teacher guidance (cf. Gough, Thomas, & Oliver, 2012). Therefore, when selecting studies for this review, similarity of methodology was not a criterion, but relevance to the topic and empirical evidence of classroom experience were. The resulting heterogeneity of the selected studies offers the opportunity to compare teacher guidance in multiple contexts and under varying circumstances, which enhances the review's ecological validity for teachers and instructional designers. However, the heterogeneity among the studies, such as the goals of studies, the educational settings, the types of interventions, and the statistical evidence, does not allow for aggregative analysis and therefore no quantative effects of teacher guidance are reported.

Furthermore, we would like to point out some limitations of our study with respect to the data collection and analysis. Having selected a body of studies from the "*questioning to learn*" approach on student questioning, a certain bias in retrieved studies should be accounted for when interpreting the results. Studies from this approach are oriented toward developing questioning as a stance and pay less attention to developing questioning as a skill. Furthermore, we only selected 36 studies on the guidance of student questioning in primary education published since 1990. We did not take into account another 78 peer reviewed empirical studies that took place in secondary and tertiary education, for the focus in this review was on primary education. Moreover, we did not include another 33 studies about aspects of student questioning published before 1990, and 36 studies from the "learning to question" paradigm that have been published since 1990. Reviews of these bodies of literature may have offered new perspectives on the emergent themes identified in this review.

Finally, another methodological limitation of this review is that over 85 % of the dataset are single-case or multiple-case studies. Although naturalistic settings contribute to the ecological validity of the findings, their contextual variation also raises the issue of the transferability of the outcomes. However, in all these studies the teachers were attempting to guide one or more phases of student questioning in classroom contexts and similar patterns of guidance were identified between different subjects, grades, countries, modes of instruction, and foci of study. The only truly discriminating factor identified between studies seemed to be the length of the intervention. Only in interventions lasting three months or longer were forms of progressive inquiry reported.

To extend our knowledge of teacher guidance of student questioning we would like to suggest some opportunities for future reviews and research. Future reviews might adopt a more aggregative methodology and search for the empirical effects of teacher guidance in one or several of the emergent themes identified in this review. Furthermore, because it seems likely students might need to develop both an inquisitive stance and questioning skills, future reviews might also consider the interplay between findings in this review and in reviews on the "*teaching to question*" approach. Further research based on the identified emergent themes might further enhance our understanding of how to guide effective student questioning. Specific questions for future research might be: How can teachers be supported in recognizing and guiding the potential in all student questions? What are the most effective ways to organize peer-support for student questioning? And how can visual tools be effectively used to support teachers in their guidance of student questioning?

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Chapter 3

Mind Map Our Way into Effective Student Questioning: A Principle Based Scenario

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ABSTRACT

Student questioning is an important self-regulative strategy and has multiple benefits for teaching and learning science. Teachers, however, need support to align student questioning to curricular goals. This study tests a prototype of a principle-based scenario that supports teachers in guiding effective student questioning. In the scenario, mind mapping is used to provide both curricular structure as well as support for student questioning. The fidelity of structure and the process of implementation were verified by interviews, video data and a product collection. Results show that the scenario was relevant for teachers, practical in use, and effective for guiding student questioning. Results also suggest that shared responsibility for classroom mind maps contributed to more intensive collective knowledge construction.

3.1 INTRODUCTION

Asking questions is a powerful heuristic for students to acquire knowledge about the world (Chouinard, Harris, & Maratsos, 2007). Student questioning, in this study defined as the process in which students generate, formulate and answer questions to seek knowledge or to resolve cognitive conflicts, seems to have multiple benefits for teaching and learning science (Biddulph, 1989; Van der Meij, 1994). Research shows that student questioning is an important self-regulative strategy that enhances intrinsic motivation, fosters feelings of competence and autonomy, and supports both knowledge construction and the development of metacognitive strategies (Chin & Osborne, 2008).

Unfortunately, as Dillon (1988) and Reinsvold and Cochran (2012) reported, teachers dominate questioning and student questions seem to be rare in classrooms. Although many teachers acknowledge the importance of student questioning, its implementation seems limited for several reasons. A major obstacle seems to be that teachers feel pressured “to cover the curriculum”, the curriculum being a set of predetermined learning goals established by National Standards, school systems, syllabi and/or teachers (Wells, 2001). Rop (2002) shows that teachers prefer direct instruction in order to achieve curriculum goals and they sometimes discourage spontaneous student questioning to prevent disruption of planned lessons. On the other hand, Zeegers (2002) finds that the teachers that are most effective in promoting student questioning facilitate students to pursue questions of personal interest. Self-formulated student questions, however, might not necessarily address curriculum goals, an issue that worries teachers. In addition to concerns about attaining curricular goals, teachers encounter two major practical challenges: (a) to organise quality guidance for a wide variety of questions, and (b) to facilitate the exchange of learning outcomes to prevent fragmented knowledge construction amongst students (Keys, 1998).

Facing these concerns and challenges, teachers seek a balance between providing structure to attain curricular goals and allowing autonomy to support student questioning (Brown, 1992; Van Loon, Ros, & Martens, 2012). In short, teachers need to guide *effective* student questioning, defined in this study as the degree in which student questions contribute to attaining curriculum goals. The aim of this study is to design and evaluate a prototype of a scenario that supports teachers in guiding effective student questioning. In addressing this aim, research questions about the relevance, practicality, and effectiveness of the scenario will be answered. Relevance concerns teachers’ perceptions that mind mapping addresses important challenges in guiding student questioning (Nieveen, 1999). Practicality consists of teachers’ perceptions that working with mind mapping is possible within the practical limitations of time, means, and knowledge (Nieveen, 2009). Effectiveness refers to the perceived support of mind mapping for realising effective student questioning (Doyle & Ponder, 1977).

3.2 THEORETICAL FRAMEWORK

Asking questions about phenomena in the world is at the heart of scientific inquiry (Chin & Osborne, 2008). Therefore, one might expect that teaching students to ask questions would play a pivotal role in science education. The reforms in science education in the US and Europe, which began in the mid-1990s, do indeed prioritize asking questions as one of the essential components of inquiry-based science teaching (e.g. National Research Council, 2000). However, even in the most inquiry-based pedagogical approaches, which intend to support students in learning how to research natural phenomena, teachers still seem to ask the questions (Osborne & Dillon, 2008). Only in the most open form of inquiry-based learning, referred to as "Open inquiry" by Bianchi and Bell (2008), are students encouraged to raise their own questions. Although many science teachers acknowledge the importance of student questioning for knowledge construction, to foster discussion, for self-evaluation, and to arouse epistemic curiosity, student questions in the classroom are not only rare but are also rarely welcomed by teachers and fellow students (e.g. Reinsvold & Cochran, 2012; Rop, 2003). Therefore teachers seem to require support to teach science in a "student question-driven classroom" (Shodel, 1995, p.278). In order to design the appropriate support for teachers we first examine the process of student questioning, the challenges this poses for teachers, which design principles support teacher guidance, and what support visual tools might offer. In the next section we describe the scenario that was developed on the basis of these theoretical findings from the literature.

3.2.1 Challenges in Teacher Guidance of Student Questioning

In general, questioning can be described as a process that consists of three subsequent phases: (a) *generating,* (b) *formulating* and (c) *answering* questions (Van der Meij, 1994). In the generating phase students become aware of a need or possibility to ask a question, caused, for example, by an experience of perplexity or a cognitive disequilibrium, and they then brainstorm about possible questions to ask. In the formulating phase students specify their need for information, when necessary they reformulate their questions, and they decide which questions to pursue. In the third phase, that of answering the question, students consult available resources and/or conduct inquiry activities. Although students are the questioners, teachers can support students in each phase.

In the generating phase teachers can support student questioning by activating and extending students' prior knowledge and allowing them to ask questions that arise from personal interest (Stokhof, De Vries, Bastiaens, & Martens, 2017). Zeegers (2002) finds that a supportive classroom culture is a prerequisite for question generation. Teachers can enhance this culture by modelling an open stance of inquiry (Commeyras, 1995). Additionally, Keys (1998) shows when students perceive topics to be relevant to their personal lives they are motivated to raise questions. Furthermore, Baumfield and Mroz (2002) report that group work seems to support question generation by facilitating the exchange of ideas and providing a sense of security, especially in small group interactions. Finally, prompts and visual tools are effective when they (a) evoke cognitive conflict or a sense of wonderment, (b) offer students the opportunity to think freely, and (c) visually support the exchange of ideas and questions (Hakkarainen, 2003).

From a curricular perspective the challenge at this phase is to align question generation to curricular goals (Stokhof et al., 2017). Spontaneous student questioning is generally unfocussed and does not necessarily address the key issues in the domain or contribute to extending students' conceptual structures (De Vries, Van der Meij, & Lazonder, 2008). Although textbook curricula offer conceptual structure, they do not allow for much student questioning (Rop, 2002). Presenting a *core curriculum* that consists of a limited number of interrelated key concepts, which represent the essential characteristics of the subject, might offer the conceptual focus to align question generation with the curriculum (cf. Scardamalia & Bereiter, 2006).

In the formulating phase, teachers usually need to mediate initially unclear and uninvestigable questions into effective student questions (Stokhof et al., 2017). Van Tassell (2001) finds that question mediation seems to require question clarification, modelling and feedback. Question formulation is fostered by a classroom culture of shared responsibility where students raise and discuss their questions collectively (Chin & Kayalvizhi, 2002). Zhang, Scardamalia, Lamon, Messina, and Reeve (2007) show that student collaboration in formulating questions increases diversity and supports the mutual adoption of questions. From a curricular perspective, all questions should be evaluated and mediated for their potential to attain curriculum goals. Beck (1998) observes that when properly valued and guided, all student questions can become valuable contributions to the curriculum.

With regard to the answering phase, Hakkarainen (2003) suggests that teachers should be aware of the progressive nature of student questioning because fact-seeking questions appear to evolve towards more profound questioning over time. Progressive inquiry emerges when answers to questions evoke new follow-up questions and thus start threads of inquiry (Zhang et al., 2007). Teachers can support progressive inquiry by activating and extending prior knowledge, pointing out important ideas and seeking questions (Martinello, 1998). The most effective approach to sustain progressive inquiry seems to be a collective effort of teachers and students, sharing, and discussing questions together and building upon each other's questions and answers, such as shown by Lehrer, Carpenter, and Schauble (2000). These authors found that a Grade 1 classroom that was willing and able to explore the process of decomposition in compost columns over the course of a whole year, sustained progressive inquiry by exchanging each other's observations, ideas, questions, and answers. Visual tools can support the phase of answering by providing a collaborative common workspace for sharing and elaborating on questions and answers (Zhang et al., 2007). From a curricular perspective, such a collaborative workspace illustrates or visualizes the way in which progressive inquiry can cover the core curriculum. To realise effective student questioning, educational design should support teachers to balance student autonomy with curricular goals.

3.2.2 Design Principles To Support Teacher Guidance

Four general design principles emerged from an extensive literature review on guiding effective student questioning: (1) define conceptual focus in a core curriculum, (2) support question generation by acknowledging potential in all questions, (3) establish a sense of shared responsibility to collectively cover a core curriculum, and (4) visualize inquiry and its relation to the curriculum (Stokhof et al., 2017). First, guiding effective student questioning is likely to require a clear but flexible conceptual focus. A core curriculum supports teachers in setting curricular goals and in making an inventory of students' prior knowledge, and it simultaneously provides opportunity for diversity in student questions. Second, supportive teachers are needed who welcome all questions and recognize their potential. Third, peer collaboration and shared responsibility enhance the generation, formulation and answering of questions. Peer guidance can support students to exchange prior knowledge, compare and improve questions, and to share and discuss answers. Fourth, visualisation seems to support all phases of the questioning process. Visual tools can help students to become aware of their prior knowledge and interests, relate questions to each other and the curriculum, and exchange their answers by creating a shared point of reference. Moreover, by visualizing and discussing learning outcomes new questions can be evoked that lead to progressive inquiry.

Building on the four design principles, we developed a *principle-based* scenario for teachers to guide effective student questioning. Given the differences in context and content between schools and their curricula, teachers should be able to adapt this scenario to their own specific classroom needs. Therefore our principle-based scenario aims to offer flexible support by providing a lesson-plan that structures the process of student questioning, but at the same time leaves open the exact content (cf. Zhang, Hong, Scardamalia, Teo, & Morley, 2011). It is expected that the principle-based scenario provides freedom to support student questioning and offers a structure for attaining curricular goals.

3.2.3 Visual Support for Teacher Guidance

An essential component of the scenario is the visual support for guiding the questioning process. Specific requirements for such a visual tool were identified in the literature (Stokhof et al., 2017). Simple visual tools, such as posters or bulletin boards, merely visualize the listing, exchange and categorisation of questions. These simple visual tools support students to remember, share and compare their questions and can help to identify subtopics and act as a stimulus for further questioning (e.g. Van Tassel, 2001).

More advanced visual tools also support the refinement of questions. For example, when teachers visualized which student questions met the required criteria in a T-bone chart and discussed their quality, students began to ask higher-level questions (Di Teodoro et al., 2011). Moreover, advanced visual tools also visualize the exchange of findings and the transformation of individual answers into collective knowledge. For example, the Driving Question Board (DQB) supported students not only to categorise their questions into specific subcategories, but also to visualize the relation between all findings, which helped students to learn about the whole topic under study (Weizman, Shwartz, & Fortus, 2008). Complex visual tools offer even more opportunity to support student questioning. Complex visual tools are not only platforms for recording and sharing questions and findings, but they also offer an adaptable flexible structure for emergent ideas and new lines of inquiry (Stokhof et al., 2017). Moreover, complex visual tools allow for both a sense of student autonomy, by offering opportunities to raise and answer questions of personal interest, as well as supporting a sense of collective responsibility by visualizing and monitoring collective knowledge development. An example of such a complex visual tool is the *Knowledge Forum* (Zhang et al., 2007). This digital platform is based on the knowledge building principles of Scardamalia and Bereiter (2006) and visually supports the exchange, discussion and elaboration of ideas. Knowledge Forum consists of a digital database in which students post their ideas as "notes", with the aim of stimulating their peers to respond with questions, suggestions, comments or answers (Zhang et al., 2007). Although this platform supports student collaboration and collective knowledge construction, it was not specifically designed to support teachers in guiding effective student questioning.

A complex visual tool seemed most appropriate for the scenario because teachers needed a flexible, adaptable tool that supported them in guiding both individual student questioning and collective knowledge building. However, the visual tool should also be easy to use by teachers and students in primary education, otherwise it would most likely not be adopted (Rogers, 2003).

After careful consideration, digital mind mapping was selected as the visual tool for the scenario. A mind map is a radial branch-like visual organiser in which concepts are structured hierarchically or associatively (Buzan & Buzan, 2006). Research has shown that mind maps have the features of a complex visual tool and are suitable for students in primary education. Furthermore, mind maps have five specific characteristics that make them particularly suitable for this scenario. First, Näykki and Järvelä (2008) have shown that mind maps support recording, exchanging and comparing information. Second, Eppler (2006) reported that mind maps have a flexible structure in which relations between concepts are easily visualized. Third, digital mind maps in particular, support quick elaborations and allow for continuous alterations in their conceptual structure (Eppler, 2006). Fourth, Tergan (2005) reported that digital mind maps could be used as data repositories in which new information can be stored and exchanged. Finally, only a limited set of rules is required for constructing a mind map: branch out from a central theme, use one word on each branch, split branches at the end, place text on top, and use colour consistently (Buzan & Buzan, 2006). For example, Merchie and Van Keer (2012) have shown that primary school students can learn and apply these rules with relative ease.

Having the features of a complex visual tool, it was hypothesised that digital mind mapping would support generating, formulating, and answering student questioning. Further, it was assumed that recording, sharing, and comparing student prior knowledge in a mind map would support generating questioning. When students become aware of the conceptual structure of their knowledge, new wonderments might be elicited and new interests raised (Hakkarainen, 2003). Mind maps were also expected to support formulating questions by visualizing and discussing criteria such as relevance and the contribution of questions to the curriculum. The relevance of questions and their contribution to the expansion of knowledge on the topic could be discussed by localizing them in the conceptual structure of the mind map. Less relevant questions are more likely to be placed on the outer branches of the mind map and might only add new information or examples on minor details. Highly relevant questions often address the relation between key concepts and might refine the conceptual structure in the mind map. Finally, mind maps were also expected to support answering questions because knowledge development can made visible by adding answers and elaborating the mind map. Students might thus become aware of the contributions of their questions to the collective knowledge, supporting a shared sense of responsibility for answering the questions, and potentially even raising new questions (e.g. Zhang et al., 2007).

3.2.4 Design of the Scenario

Based on four design principles, a scenario to guide effective student questioning was developed that consisted of a teacher preparation phase, three phases of questioning, and an evaluation phase. This sequence of phases is similar to that of “an interactive approach to science”, as developed by Biddulph and Osborne (1984). In each phase mind mapping was used to visualize the core curriculum and the collective process of questioning and answering.

In Phase 1 the teachers prepare a core curriculum around a chosen central topic. The intended output is a visualized core curriculum represented as an *expert mind map*. An expert mind map serves primarily as a point of reference for teachers to guide student questioning. This means that to allow for optimal student autonomy, teachers use an expert mind map only implicitly to structure and support student input in later phases. Teachers also prepare an introductory activity that is expected to raise students’ interest in the topic and is aimed to activate students’ prior knowledge about important concepts and issues.

The aim of Phase 2 is to activate and record students' prior knowledge and to prompt students to generate questions. First, the topic is introduced to the whole class by means of an activity that raises interest and activates prior knowledge, for example by demonstrating an experiment or discussing an ambiguous claim. Students are then asked to individually note all the concepts they associate with the topic. They subsequently exchange their notes in small groups before sharing them with the whole class by making a collaborative inventory of concepts in an unstructured "field of words". Before structuring the collective prior knowledge, students are requested to record their individual prior knowledge in an *individual mind map*. Teachers then support students in structuring the field of words into clusters and, subsequently, into mind map branches, alternating between small group work and whole class discussion. Together, all mind map branches form a *classroom mind map* that visualizes collective conceptual prior knowledge as a structure of key concepts, examples, details, and their mutual relations.

In Phase 3, student questions are generated, exchanged, evaluated, selected and reformulated. First, students are presented with a *question-focus*, which is a prompt in the form of a statement or visual aid that attracts and focuses student attention and stimulates questioning (Rothstein & Santana, 2011). Prompted by a question-focus, students brainstorm in small groups about potential questions. Every student is invited to generate as many questions as they can think of, and all input is recorded. Then, students in various groupings discuss the relevance and learning potential of the questions and their classroom mind map is used as a shared point of reference. The most relevant and promising questions are selected during classroom discussion and, when necessary, further clarified and reformulated by students with support from the teacher. Finally, the selected questions are visualized in the classroom mind map and each student adopts one question for further inquiry.

In Phase 4, the selected and adopted student questions are answered. Students investigate questions individually or in dyads. Some questions are investigated by using primary sources, such as performing an experiment, doing observations, collecting data on a fieldtrip or interviewing an expert. Other questions are explored with secondary sources such as dictionaries, encyclopaedias, books, websites or video. Students use *question worksheets* to record: their question; which concept in the classroom mind map it addresses; a prediction for an answer; which resources might be supportive, and what (preliminary) answers have been found. Students present the answers to their peers and outcomes and evoking possible follow-up questions. To visualize collective knowledge construction, answers are also integrated in the classroom mind map by either elaborating or restructuring the mind map. Ideally, new follow-up questions emerge when discussing the answers, and students can adopt these questions by starting a new cycle of inquiry.

Finally, in Phase 5 learning outcomes are evaluated. By comparing the expert mind map with the final classroom mind map, teachers and students can evaluate the degree to which the core curriculum has been covered. Furthermore, students construct a post-test individual mind map. Students are provided with pencil and paper and allowed 45 minutes to visualize their knowledge in a mind map. By comparing pre- and post-test individual mind maps and that of the expert mind map, teachers and students can assess individual learning outcomes and determine the extent to which curriculum goals are attained by all students.

3.2.5 Testing the scenario

To assess the value of the scenario for guiding effective student questioning, both *structure fidelity* and *process fidelity* of implementation were measured (cf. O'Donnell, 2008). Structure fidelity describes the degree to which teachers worked with the scenario, and this is operationalized as *adherence* — the extent to which teachers' perform the suggested activities in the scenario as intended — and *duration*, which refers to the number, length or frequencies of the performed activities (Mombray, Holter, Teague, & Bybee, 2003). Process validity describes how teachers perceived the support of mind mapping in the scenario in terms of guiding effective student questioning and how it was operationalized in the variables of *relevance, practicality* and *effectiveness.* Relevance refers to the teachers' perceptions that mind mapping addressed important challenges in guiding student questioning (Nieveen, 1999). Practicality consists of the teachers' perceptions that working with mind mapping was possible within the practical limitations of time, means and knowledge (Nieveen, 2009). Effectiveness refers to the perceived support of mind mapping for realising effective student questioning (Doyle & Ponder, 1977).

Although process fidelity is the focus of this study, the degree of structure fidelity is taken into account with the aim of relating the teacher's performance to his or her perceptions, and to make comparisons between cases. Taken together, the three process variables assess the quality of the scenario and serve to answer the following research question: What is the relevance, practicality, and effectiveness of digital mind mapping in a principle-based scenario for guiding effective student questioning?

3.3 METHOD

The research was set up as a multiple case design study in which a prototype of a scenario to support guidance of effective student questioning was developed, implemented and evaluated in close collaboration with practitioners in primary education (McKenney & Reeves, 2012). The study aims to evaluate the process of implementation of the prototype in order to improve it.

3.3.1 Participants

The study participants comprised of 12 teachers and their 268 students from Grades 3–6, distributed over nine classrooms in two primary schools in a suburban district in the Netherlands. The group of teachers consisted of five males and seven females aged 28 to 56 years old. All participants were experienced teachers with between 10 and 32 years of teaching experience. Most teachers worked full-time, but five teachers worked part-time from two to four days a week. Each classroom was regarded as a separate case, so in total nine cases participated. Cases 1–9 were selected, first because their teachers had expressed a need for support in guiding effective student questioning, and second because they were able and willing to test the scenario from the perspective of the end-users (McKenney & Reeves, 2012).

The scenario was tested for the social science curriculum, which is mandatory in the Netherlands for primary education and comprises subjects such as history, geography, physics, and biology. Teachers in both schools taught project-based social science for periods of six to eight weeks, but had no previous experience with student questioning. Teachers in school A had some experience in the use of mind maps to visualize learning content. All cases were equipped with the *I-Mind Map* 6™ software and an interactive white board (IWB) to project and manipulate computer-images on a large touchscreen in front of the whole class.

3.3.2 Training

All teachers were trained in two preparatory sessions. In a first two-hour session teachers were informed about the general steps in the scenario, they practiced and discussed phases of generating, formulating, and evaluating questions, and explored how the scenario could be implemented in their specific classrooms. In a second two-hour session teachers collectively designed an expert mind map and introductory activities. The topics chosen by school were: “Health” for a combined Grade 3–4 and “The River” for Grades 5 and 6. School B selected the topic: “My Body” for six combined classes of Grades 4–5–6.

3.3.3 Data collection and analyses

Data was collected during a six-week period in the spring of 2014. In each case all classroom activities from Phases 2–5 of the scenario were video-recorded. All participating teachers were involved in the collective design sessions in Phase 1, which were audio-recorded. After completing Phase 5, individual semi-structured interviews were held with all participating teachers. The interviews focused on teachers’ perceptions of the relevance, practicality, and effectiveness of the five phases of the scenario. For example, teachers were asked about their perceptions of the practicality of Phase 2: “To what extent do you consider making a classroom mind map to be effective as an introduction to the topic?" An overview of all interview questions can be found in Appendix 1. To triangulate video and audio data, classroom products were collected, such as individual and classroom mind maps produced in the several phases of the scenario. In addition, we collected the worksheets of students that administered the questions they posed and the answers they found.

The analysis took account of several variables for fidelity of structure and process (Table 3.1). The fidelity of structure was determined first. The adherence was analyzed by observing the video- data and using a checklist of suggested activities for each phase (Appendix 2). To ensure interrater reliability a sample of approximately 20% of video recordings was independently coded by two researchers. An intercoder agreement of $\kappa = .90$ for the sample was established. After discussing differences, the remainder of the video data was coded by the first author. The video data on adherence could also be triangulated for most activities by product collection. For example, multiple versions of the classroom mind map, which showed increasing elaboration, confirm its use in Phase 4. Furthermore, duration was measured by logging the minutes in the videos spent on the various activities. The total amount of time spent on the scenario in each case for each phase was then calculated, rounding the totals up to five minutes for easy comparison.

Fidelity of process was mainly determined by coding the transcriptions of the teacher interviews and the design sessions. The variables relevance, practicality, or effectiveness, as shown in Table 3.1, were operationalized as coding categories in an analysis matrix to determine for each segment of the transcript: the phase to which it referred, the variable addressed, and whether the perceived value was positive, negative or mixed (Appendix 3). To ensure interrater reliability of this matrix, two raters independently used MAXQDA11™ software to score 20% of the interview transcripts. An average score of $\kappa = .83$ was calculated for all coding categories, indicating a strong agreement among raters. The first author then coded the remainder of the transcripts using MAXQDA11™. Coded data was then qualitatively analyzed to distinguish trends, similarities, differences, and peculiarities for each coding category.

Classroom products and video data were used to triangulate findings for the variables practicality and effectiveness. Classroom products such as question-worksheets provided additional data about individual student questioning in Phase 4. The development of classroom mind maps was analyzed by comparing versions in terms of similarity of content and structure. In preparation for the interviews, teachers were asked to compare pre- and post-test student mind maps with their expert mind map and to determine the degree to which their curricular goals had been achieved. Teachers' perceptions of student learning outcomes were discussed during the interviews. When the video data revealed the absence of suggested activities, this was also discussed during the interviews in relation to their perceived practicality.

Table 3.1. Variables and Indicators for Structure and Process Fidelity of Scenario

Phase in scenario	Based on design principle(s)	Structure fidelity		Process fidelity		
		Adherence	Duration	Relevance	Practicality	Effectiveness
Phase 1: Prepare core curriculum	Conceptual focus Visualize curriculum	Construct expert mind map Prepare introduction	Amount of time spent on Phase 1	Perceived need for selecting & visualizing (core) curriculum	Perceived ease to select & visualize (core) curriculum	Perceived support for selecting & visualizing (core) curriculum
Phase 2: Visualize prior knowledge & generating questions	Conceptual focus Collective effort Visualize curriculum Acknowledge potential	Introduction Inventory prior knowledge Individual mind maps Cluster concepts Form branches Construct classroom mind map	Amount of time spent on Phase 2	Perceived need for visualizing prior knowledge and generating student questions	Perceived ease to visualize prior knowledge and generate student questions	Perceived support for visualizing prior knowledge and generating student questions
Phase 3: Formulate questions	Conceptual focus Collective effort Visualize curriculum Acknowledge potential	Question brainstorm Exchange questions Evaluate questions Select questions Reformulate questions Adopt questions	Amount of time spent on Phase 3	Perceived need in guiding question formulation	Perceived ease to guide question formulation	Perceived support for guiding question formulation
Phase 4: Answer questions	Conceptual focus Collective effort Visualize curriculum Acknowledge potential	Predict answers Select sources Find/construct answers Present answers Discuss answers Adapt classroom mind map Discuss progressive inquiry	Amount of time spent on Phase 4	Perceived need for building collective knowledge on the basis of student answers	Perceived ease to build collective knowledge on the basis of student answers	Perceived support for building collective knowledge on the basis of student answers
Phase 5: Evaluate learning outcomes	Conceptual focus Collective effort Visualize curriculum Acknowledge potential	Evaluate classroom mindmap Evaluate student mindmaps	Amount of time spent on Phase 5	Perceived need for evaluating collective and individual learning outcomes	Perceived ease to evaluate collective and individual learning outcomes	Perceived support for evaluating collective and individual learning outcomes

3.4 RESULTS

The following discussion will first consider the fidelity to structure of the scenario in terms of adherence and duration, before presenting findings about fidelity of process, operationalized as relevance, practicality and effectiveness.

3.4.1 Structure Fidelity of Implementation

Table 3.2 shows observed adherence to all suggested activities of the scenario for each case. Phase 1 is not included because these preparatory meetings of the teachers were chaired by the first author and were therefore executed as intended. For Phase 2 the data show that all teachers organised their students to collect and cluster prior knowledge in order to co-construct a classroom mind map. Furthermore, a question brainstorm was held in all cases and students were asked to construct a pre-test individual mind map. With the exception of Case 5, all the activities of Phase 3 were observed in all cases. Unfortunately, due to a malfunctioning camera all video recordings for Case 5 in Phase 3 were lost, although product collection confirms that this phase was executed. In Phase 4, differences in adherence between cases became apparent. The question worksheet was not used in Case 1. In Cases 2 and 3 there was missing data on predicting answers. The most remarkable difference in Phase 4, however, was that the classroom mind map was not adapted or elaborated in Cases 5 and 7. This was confirmed by analysis of the classroom mind maps. Another remarkable finding was the relatively limited number of follow-up questions in most cases, except for Cases 4 and 9. In Phase 5 only three teachers evaluated the development of the classroom mind map with the students (Cases 1, 3 and 4). Individual mind maps were not evaluated with the students as suggested, although almost all students made pre and post-test mind maps. We conclude that, in general, the teachers adhered to the structure of the scenario, but adherence decreased in later phases of the scenario.

Table 3.2. Adherence to Suggested Classroom Activities in Scenario

Classroom activities		Cases								
		1	2	3	4	5	6	7	8	9
Phase 2	Introduction	+	+	+	+	+	+	+	+	+
	Inventory associations	+	+	+	+	+	+	+	+	+
	Individual mind map	+	+	+	+	+	+	+	+	+
	Cluster concepts	+	+	+	+	+	+	+	+	+
	Form branches	+	+	+	+	+	+	+	+	+
	Construct classroom mind map	+	+	+	+	+	+	+	+	+
Phase 3	Question brainstorm	+	+	+	+	+	+	+	+	+
	Exchange questions	+	+	+	+	0	+	+	+	+
	Evaluate questions	+	+	+	+	0	+	+	+	+
	Select questions	+	+	+	+	0	+	+	+	+
	Reformulate questions	+	+	+	+	0	+	+	+	+
	Adopt questions	+	+	+	+	+	+	+	+	+
Phase 4	Predict answers	0	0	0	+	+	+	+	+	+
	Select sources	0	+	+	+	+	+	+	+	+
	Find/construct answers	+	+	+	+	+	+	+	+	+
	Present answers	+	+	+	+	+	+	+	+	+
	Discuss answers	+	+	+	+	+	+	+	+	+
	Adapt classroom mind map	+	+	+	+	-	+	-	+	+
	Discuss progressive inquiry	-	-	-	+	-	-	-	-	+
Phase 5	Make individual mind map (post)	+	+	+	+	+	+	+	+	+
	Evaluate classroom mind map	+	-	+	+	-	-	-	-	-
	Evaluate individual mind map	-	-	-	-	-	-	-	-	-
Total of observed activities (maximum is 22)		18	18	19	21	13	19	18	19	20

Note: + is adhered; - is not adhered; 0 is missing data.

Duration, which was operationalized as the amount of time each case spent on working on the scenario, is presented in Table 3.3. Over a six-week period, teachers were scheduled to work on the scenario for approximately three hours each week. Most time was spent on Phase 4, in which students had to find or construct answers to their questions and subsequently present and discuss them in class. Although in only three cases did teachers discuss the development of the classroom mind map in their class, all teachers allotted time for students to construct their individual mind maps as pre- and post-test in Phase 5. When comparing cases, a significant difference was only observed for Phase 4 in Case 1.

Table 3.3. Duration of Work on Scenario

Case		1	2	3	4	5	6	7	8	9
Phase 2	Minutes	240	220	230	245	240	235	245	240	235
	%	22	21	21	22	23	22	24	22	22
Phase 3	Minutes	90	85	90	95	90*	90	85	90	90
	%	8	8	8	9	8*	9	8	8	8
Phase 4	Minutes	300	670	660	670	675	660	640	680	670
	%	28	64	61	61	63	63	62	64	62
Phase 5	Minutes	90	60	95	90	60	60	60	60	60
	%	8	6	9	8	6	6	6	6	6
Total	Minutes	1070	1045	1075	1095	1065	1045	1030	1070	1085
	%	100	100	100	100	100	100	100	100	100

Note: * based upon teacher's self-report because of missing video-data

3.4.2 Process Fidelity

How teachers perceived relevance, practicality and effectiveness of mind mapping for guiding effective student questioning is summarised in Tables 3.4, 3.5 and 3.6. In many cases teachers perceived the variables as either positive (+) or negative (-). However, for some variables in certain phases, teachers described having perceived both positive and negative aspects, which is indicated as mixed (+/-). For example, the teacher in Case 1 considered it to be relevant for most pupils to make an inventory of their own individual prior knowledge in Phase 2, but had some reservations about whether this would be suitable for certain pupils. More qualitative details and examples will be presented on each phase for these variables.

Perceived relevance

Table 3.4. Perceived Relevance

Perceived Relevance	*Cases*								
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
Phase 1	+	+	+	+	+	+	+	+	+
Phase 2	+/-	+	+	+/-	+/-	+	+	+	+
Phase 3	+	+	+	+	+	+	+	+	+
Phase 4	+/-	+	+	+	+/-	+	+	+	+
Phase 5	+	+	+	+	+	+	+	+	+

All teachers perceived the preparation of an expert mind map in Phase 1 as relevant because it addressed their need to acquire a conceptual overview of the topic (Table 3.4). Previously, teachers had mainly followed instructions from the manual for these projects, regarding the prescribed educational activities as the stepping-stones for the curriculum. However, in so doing, the teachers had lacked an overview as to what knowledge students were supposed to acquire from these activities. By exploring and discussing the topic, and selecting a core curriculum, teachers felt they could conceptually rise above a mere sequence of activities. As one teacher said: “I used to look several times a day [in the manual] to keep an overview [on which activities I am supposed to offer to the students], but since we made the expert mind map I haven’t looked once”.

In Phase 2, all but two teachers perceived making an inventory of students’ prior knowledge by means of a classroom mind map as relevant. Seven teachers mentioned that the classroom mind map addressed their need for an overview of students’ prior knowledge and offered a conceptual focus to elicit student questions. The other two teachers felt somewhat constrained in their teaching because they felt too much time was spent on “what was already known” when they would have liked to introduce new knowledge.

In Phase 3 teachers felt the need for an efficient method to guide student questioning to address curricular topics. In the past, most teachers had experienced guiding question formulating as both time-consuming and not always effective. All but two teachers perceived that question brainstorming produced a valuable reservoir of questions, from which many relevant questions for learning the curriculum could be selected.

With regard to Phase 4, teachers expressed two needs: first, to support and monitor student progress in answering their questions and, second, to guide an effective exchange of learning outcomes. Teachers perceived their classroom mind maps as providing an overview of which questions were addressed by whom, but they did not specifically allow for monitoring students’ individual progress. To address this need to visualize the progress of the individual students, one of the teachers invented a “monitor-board”. On this board every student placed his name card on specific step in the questioning process he or she was working on: formulating questions, searching information, processing information, preparing presentations or giving presentations. Four of the five colleagues in her school readily adopted this monitor-board.

Phase 5 of the scenario was designed to support teachers in evaluating the individual and collective learning outcomes with their students. Teachers were encouraged to discuss the development of collective knowledge as visualized by versions of the classroom mind map, or individual knowledge development as visualized in pre and post-test student mind maps. In the interviews all teachers stated that they perceived evaluating learning outcomes with mind maps to be relevant (Table 3.4).

Perceived practicality.

Table 3.5. Perceived Practicality

Perceived Practicality	*Cases*								
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
Phase 1	+	+	+	+	+	+	+	+	+
Phase 2	+/-	+	+	+	+	+	+	+	+
Phase 3	+	+	+	+	+	+	+	+	+
Phase 4	+/-	+	+	+	+/-	+	+/-	+	+/-
Phase 5	+/-	+	+/-	+	+/-	+	+/-	+	+

Phase 1 was perceived as practical because teachers managed in one two-hour session to determine the core curriculum in an expert mind map. Some teachers indicated that they sometimes found it difficult to let go of their personal interpretations of the topic and to allow alternative perspectives of its conceptual structure, but all agreed the resulting discussion had been beneficial for their understanding (Table 3.5).

Constructing the classroom mind map in Phase 2 was generally perceived as practical, especially when teachers found a balance between alternating whole class and small group work to keep students active and engaged. Teachers appreciated the possibility in the principle-based scenario to make "short-cut" decisions that could speed up the construction process. For example, as one teacher explained: "You can discuss for hours how to structure concepts in clusters, but you can also suggest [the names of] the clusters [in other words, give students the key concepts on the head branches of the mind map], and let the students figure out how to structure their concepts accordingly".

Although most students needed teacher support when evaluating the quality of questions in Phase 3, teachers perceived the classroom mind map as practical visual support for this discussion. The classroom mind map helped to visualize the relevance of a question for the curriculum and to estimate its potential learning outcome.

For the exchange of answers in Phase 4, the classroom mind map was used in seven cases, although perceptions on its practicality differed among these teachers (Table 3.5). The four teachers who themselves took the responsibility to expand the classroom mind map struggled to find time to integrate the findings of the students. A complicating factor in these cases was that many students only produced answers and presentations in the last weeks and thus elaboration of the classroom mind map was delayed to the last moment. In Cases 2, 4 and 6 teachers made weekly alternating groups of students responsible for elaborating the classroom mind map. In Cases 5 and 7 classroom mind maps were only used to relate questions to the curriculum, but these were not expanded. In Case 5 this was a result of the prolonged absence of the regular teacher. In Case 7 the teacher chose to organise an alternative exchange of findings by means of a "mini-conference".

In contrast to the unanimously expressed need for evaluation in Phase 5, only in Cases 1, 3 and 4 did the teachers discuss the collective knowledge development with their students, as visible in versions of the classroom mind map. The individual knowledge development of students, which might become apparent by comparing pre and post-test personal mind maps, was not discussed in any of the cases. Teachers explained that this was primarily due to time-concerns because they were still busy wrapping up the projects in the last week.

Perceived effectiveness.

Table 3.6. Perceived Effectiveness

Perceived Effectiveness	*Cases*								
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
Phase 1	+	+	+	+	+	+	+	+	+
Phase 2	+/-	+	+	+	+	+	+	+	+/-
Phase 3	+	+	+	+	+	+	+	+	+
Phase 4	+/-	+	+	+	+/-	+	+/-	+	+
Phase 5	-	+	+	+	+/-	+	+/-	+	+

Phase 1 was perceived as effective by all teachers because constructing an expert mind map not only deepened their understanding of the topic and enhanced their self-confidence in guiding student questions that addressed the topic, but also provided practical experience for the upcoming process of constructing a classroom mind map together with students (Table 3.6).

The classroom mind map was considered by all teachers to be effective for visualizing students' collective prior knowledge in Phase 2. In seven cases the classroom mind map was perceived to be effective as a question focus for the students' question brainstorm. In two cases teachers chose objects and photomontages as alternative question foci. However, in these cases teachers were somewhat dissatisfied with the resulting question output, classifying many questions as insufficiently focused on the topic.

In Phase 3, teachers felt that being able to generate, select and reformulate questions with the whole class was more effective, compared to a one-to-one teacher-student approach. Moreover, by allowing students to adopt each other's question, all students were able to work on relevant questions of their own interest, even when they had difficulty in formulating questions. The two teachers who had perceived their question brainstorm as less successful indicated that they struggled to support students in reformulating their questions, but that they had eventually succeeded in having a sufficient number of relevant questions for students to choose from.

Although some teachers struggled to organise collective knowledge construction in the classroom mind map, all teachers generally regarded Phase 4 as effective because all student questions were answered, exchanged and discussed. In Cases 2, 3, 4 and 6, where the students' collective responsibility for the knowledge construction was well organised, the classroom mind maps were elaborated more continuously and the numbers of added concepts were the highest among the cases, as shown in Figure 3.1. The mean number of questions under investigation in each classroom was about 16, with outliers of 10 and 28 questions in Cases 1 and 7 respectively (Figure 3.1). Remarkably, only two teachers, from Case 4 and Case 6, expressed some concerns about the low number of follow-up questions and wondered why students seldom raised them.

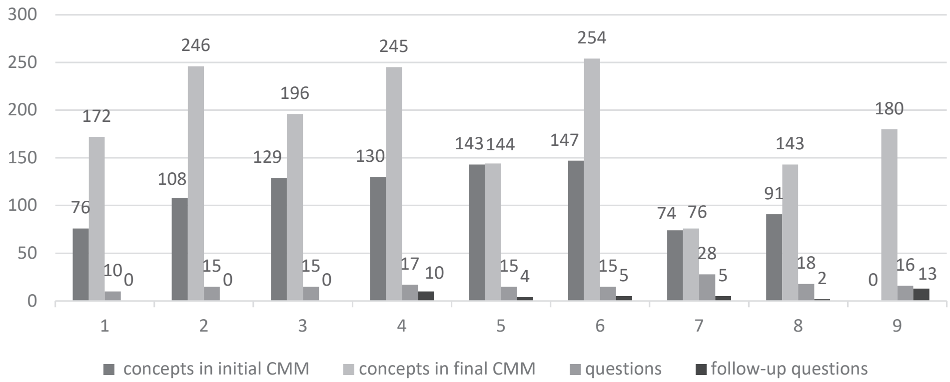

Figure 3.1. Development of number of questions and concepts in classroom mind maps

In Phase 5, the small number of teachers that did evaluate the development of collective knowledge discovered that many students were able to explain the contribution of specific questions to elaborating the classroom mind map. However, students also mentioned that without the example mind map in sight, it was sometimes hard to recollect all the specific concepts in the classroom mind map beyond the head branches.

The student learning outcomes of Phase 5 were therefore primarily evaluated with the teachers during interviews to determine the teachers' perception of effectiveness. In preparation for these interviews teachers were requested to compare student pre- and post-test mind maps and the expert mind map. To help teachers compare, some indicators for the quality of the mind map were suggested. As quantitative measures, teachers could compare the number of head branches, the number of concepts, and the number of layers in branches; and as qualitative measures, the use of key concepts and specific terminology from the expert mind map. During the interviews teachers used examples to illustrate their perceptions of students' learning progress. One of these examples is shown in Figure 3.2. When carrying out the comparison, the teacher noticed that the number of concepts had doubled, and more terminology and key concepts from the expert mind map were embedded in the post-test mind map. For example, for the key concept "diseases", the student added terms such as "hereditary", "contagious", and "remedy". In addition, the mind map structure became more refined and elaborated, as is visible in the increase in the number of layers, from 2–3 levels for each branch to 3–6 levels.

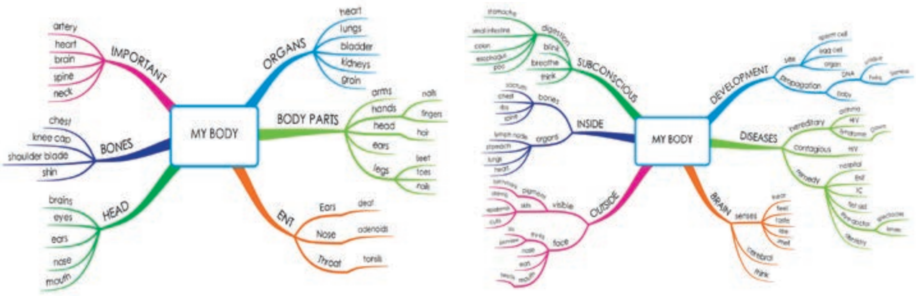

Figure 3.2. Example of comparison between pre and post-test student mind maps

With the exception of Case 1, teachers were generally satisfied with the progress students had made in their mind maps. Teachers frequently presented examples to show that students had embedded more key concepts in the post-test mind maps and the structure of the mind map was often elaborated and refined. However, teachers expressed concerns that mind maps might not always represent the actual knowledge students possessed. In most cases teachers identified one or two students who had great difficulty constructing mind maps, but who, on the other hand, had shown that they possessed profound knowledge of the topic during their presentations. Teachers suggested that although they considered mind mapping to be a useful method to assess conceptual knowledge, it might not be a valid instrument for summative assessments for all students. In Case 1, the teacher was dissatisfied with the learning outcomes of her students and was disappointed because many students failed to use some of the specific key concepts she had added to the classroom mind map. However, the results on adherence showed that students in Case 1 spent considerably less time on researching their questions and exchanging answers than in other cases.

3.5 DISCUSSION

The aim of this study was to answer the following research question: What is the relevance, practicality, and effectiveness of digital mind mapping in a principle-based scenario for guiding effective student questioning? Results show that teachers adhered to most of the suggested activities of the scenario, with the exception of evaluating learning outcomes with students, and managed to finish the project within the time available. Moreover, most teachers perceived mind mapping as relevant, practical, and effective for guiding effective student questioning, although two teachers were critical of the practicality and effectiveness of mind mapping for all phases. We therefore conclude that mind mapping can support teachers in guiding student questions to contribute to curricular goals.

Although this study set out to test the functionality of mind mapping in a principle-based scenario, some more general observations could also be made about teacher guidance of effective student questioning. First, a thorough preparation in which teachers explore, discuss, and determine a conceptual focus for student questioning was effective in boosting teachers' self-confidence about guiding student questioning to contribute to curricular goals. This is in keeping with the findings of Zeegers (2002) and Diaz (2011) who reported that teachers' self-efficacy to guide student questioning was correlated with their domain knowledge. Second, in this study a visualized inventory of students' prior knowledge was the most effective question focus for generating relevant student questions. However, to our knowledge, this finding has not been reported in previous literature, and requires more thorough research to be validated. Third, the use of question brainstorms, as suggested by Rothstein and Santana (2011), was highly effective for generating many student questions. Bringing students temporarily into a "question-modus", in which their only focus is on generating questions, seemed to elicit creativity and wonderment in student questioning. Question brainstorms might thus overcome the phenomenon, which was reported by Scardamalia and Bereiter (1992), that students would restrict themselves to fact-seeking questions that might easily be answered because of their concerns about how to conduct subsequent inquiries. On the contrary, the reservoir of questions produced in the question brainstorm allowed many students to adopt questions that interested them and challenged their answering skills. Fourth, making students mutually responsible for each other's questions and answers was found in this study to be the most effective strategy to establish a continuous process of collective knowledge construction. This is congruent with the findings of Zhang et al. (2007), who reported that shared responsibility is an important precondition for effective collective knowledge construction. Fifth, although a collective visual platform, such as a classroom mind map, might support a mutual feeling of responsibility for knowledge construction, it is not sufficient in itself. Our results suggest that a culture of mutual responsibility also requires that teachers transfer some of their classroom control to the students. Harris et al. (2011) and Hume (2001) have reported similar observations. Finally, the evaluation of learning outcomes in mind maps was primarily carried out by the teachers with the aim of the "assessment of learning". Although this generally supported teachers in evaluating student' learning outcomes, students themselves missed out on the opportunity to evaluate their own mind maps. Our finding that most teachers did not provide their pupils with feedback on task is not uncommon, as Hattie and Timperly (2007) have shown. However, this is unfortunate because Von Secker (2000) has shown that overall student' results would rise by 17% if student self-evaluation of learning activities was emphasised in inquiry-based science units (cited in Bybee et al., 2006). Moreover, from the perspective of "assessment for learning", mind maps may have great potential to make students aware of their evolving knowledge structures (cf. Black, Harrison, Lee, Marshal, & Wiliam, 2004).

To correctly interpret the findings presented here, we would like to point out some methodological limitations of our study. First, participating teachers were willing and able to try-out the scenario, which might have influenced their objectivity. On the other hand, evaluation by voluntary practitioners is recommended when testing educational designs in the prototyping phase because non-voluntary participants might be unwilling to stretch the design to its full potential, thus exposing its strengths and its flaws (Nieveen, 2009). Second, the quality of the scenario is primarily measured by teachers' perceptions. This is ecologically valid in terms of evaluating teachers' experiences but, on the other hand, teacher-perception is a subjective measure for the quality of student learning outcomes, although findings were triangulated by video-recordings and product collection. Therefore, future research should also seek objective measures to determine the success of the scenario for student learning outcomes.

Another limitation, with regard to the aims of the study, was that none of the cases demonstrated progressive inquiry, the self-perpetuating process of questioning and answering. There are several possible explanations for this finding. First, the duration of the intervention might have been a factor. The projects is this study only lasted for six weeks, whereas most studies that report progressive inquiry lasted for a semester or longer (Hakkarainen, 2003; Lehrer et al., 2000). A second factor could be that questioning was perceived as a task rather than a stance. Students might have perceived asking questions as a task, just like the other assignments at school. When the answer was found, the students might have thought that the "the job was done". In contrast, progressive inquiry requires that students perceive answers as stepping-stones to new questions. Therefore, merely allowing students to raise their own questions might be insufficient for them to develop "questioning as a stance" (Cochran-Smith & Lyte, 2009, p.3). Third, the scenario contained no specific instructions for teachers to guide progressive inquiry. Therefore, more research seems to be necessary to establish how teachers can foster progressive inquiry during collective knowledge construction. Possible strategies might entail adopting critical peer-evaluation of answers, teacher modelling of progressive inquiry, or challenging students to present both answers as well as follow-up questions during the answering phase.

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Chapter 4

Using Mind Maps to Make Student Questioning Effective: Learning Outcomes of a Principle-Based Scenario for Teacher Guidance

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ABSTRACT

Student questioning is an important learning strategy, but rare in many classrooms, because teachers have concerns if these questions contribute to attaining curricular objectives. Teachers face the challenge of making student questioning effective for learning the curriculum. To address this challenge a principle-based scenario for guiding effective student questioning was developed and tested for its relevance and practicality in two previous studies. In the scenario, which consists of a sequence of pedagogical activities, mind maps support teachers and students to explore and elaborate upon a core curriculum, by raising, investigating, and exchanging student questions. In this paper, a follow up study is presented that tested the effectiveness of the scenario on student outcomes in terms of attainment of curricular objectives. Ten teachers and their 231 students participated in the study. Pre and posttest mind maps were used to measure individual and collective learning outcomes of student questioning. Findings show that a majority of students progressed in learning the core curriculum and elaborated upon it. The findings suggest that visualizing knowledge construction in a shared mind map, supports students to learn a core curriculum and to refine their knowledge structures.

4.1 INTRODUCTION

Intellectual curiosity, referring to student's motivation to comprehend and engage in cognitively demanding tasks, is identified as a third major predictor for success in academic performance, next to intelligence and effort (Von Stumm, Hell, & Chamorro-Premuzic, 2011). Adults, such as parents and teachers, can have a pivotal role in supporting or inhibiting intellectual curiosity in students (Chak, 2002). One of the strategies to arouse intellectual curiosity is to encourage students to ask Sincerely Information Seeking (SIS) questions (Greasser & Wisher, 2001). SIS questions are raised by students with the aim to enlarge their knowledge base or to resolve cognitive conflicts (Van der Meij, 1994). SIS questions express a genuine interest and intrinsic motivation of students to inquire into a topic (Jirout & Klahr, 2011).

Although student SIS questioning is deemed important, it is rarely observed in classrooms (Engel & Randall, 2009). Although many teachers acknowledge the importance of intellectual curiosity, in practice they struggle to balance freedom for students SIS questioning with curricular pressures (Engel & Randall, 2009). In education, therefore, the challenge emerges to build a bridge between the intellectual curiosity and personal interests of students (the student perspective), and the responsibility for coverage of the curriculum and attainment of learning goals (the teacher perspective). Because teachers have a pivotal role in building this bridge, they need support to guide *effective student questioning,* defined as the degree to which student questions emerging from intellectual curiosity contribute to learning curriculum objectives as set by the teacher, handbook or national standards.

To support teachers in guiding effective student questioning a principle-based scenario was developed in a design-based research project (Stokhof, De Vries, Bastiaens, Martens, 2017; Stokhof, De Vries, Martens, Bastiaens, 2017). A principle-based scenario provides a sequence of pedagogical activities, which supports teachers to translate design-principles into concrete classroom teaching, and to make adaptive decisions to accommodate activities to local contexts, needs and possibilities (cf. Wen, Looi, & Chen, 2012; Zhang, Hong, Scardamalia, Teo, & Morley, 2011). The aims of the scenario were to encourage students to generate and investigate SIS questions, to align student questioning to the curriculum objectives, and to support and monitor student learning outcomes. In the scenario mind mapping was selected as the visual tool which teachers supported to: a) define and visualize curriculum objectives, b) elicit prior student knowledge, c) generate and discuss student questions, d) guide collective knowledge construction, and e) monitor and evaluate the development of both individual and collective knowledge.

First, the design-principles for the scenario were identified in a review study (Stokhof et al., 2017a). Then, a follow-up study was conducted that focused on the development and refinement of a prototype of the scenario for teacher guidance in several iterations of design, implementation, evaluation and redesign (Stokhof et al., 2017b). The evaluation focused on the relevance, practicality and process effectiveness of the scenario. The next and final step in the development process of the scenario was to identify the impact of the intervention on student learning outcomes (cf. Nieveen, 2009). Therefore, this study explores if and to what extent students can attain curricular goals by raising and exploring SIS questions, when guided by the scenario. In the next section the design-principles of the scenario and rationale for the use of mindmapping as tool for measuring learning outcomes are described and explained.

4.2 THEORETICAL FRAMEWORK

4.2.1 Design-principles for effective student questioning.

To design a scenario that could support teachers in guiding effective student questioning, first the literature on the role and effects student questioning was reviewed in previous study (Stokhof et al., 2017a). Four design principles emerged that promote and support a classroom culture in which student questioning can effectively occur: a) define a core curriculum, b) support question generation, c) establish a shared responsibility, and d) visualize collective knowledge construction.

The first design principle claims that teachers should identify a core curriculum for the topic under study. The challenge for teachers is to define a conceptual focus, that allows both freedom for students' intellectual curiosity and structure for aligning their personal questioning to curriculum objectives. Applebee (1996) suggests that a few core concepts could form the basis for such a curriculum. By limiting a curriculum to its core, students have the opportunity to explore and to elaborate upon these core concepts. Similarly, Scardamalia (2002) considers "Big Ideas" to be a conceptual structure which allows for student inquiry. Mitchell, Keast, Panizzon, and Mitchell (2017) demonstrate that Big Ideas allow teachers to a) introduce and organize content, b) connect the topic to student experience, c) provide the basis for restructuring existing ideas Moreover, identifying and discussing a core curriculum in preparation of their lessons is expected to deepen teachers' domain knowledge and to provide them with a conceptual focus for guiding their students' questions (cf. Mitchell et al., 2017; Zeegers, 2002; Zhang, Scardamalia, Reeves, & Messina, 2009).

The second design principle states that teachers should support question generation by making students aware of their prior knowledge and by encouraging and acknowledging all questions. When teachers guide students to activate, structure and exchange their prior knowledge, this raises students' awareness of possible gaps in their knowledge (Van Tassel, 2001). This awareness of the "not-yet known" is expected to elicit students' perplexity and questioning (Greasser & Wisher, 2001). Therefore, teachers have a pivotal role in supporting the actual generation of questions (Stokhof et al., 2017a). When teachers value all types and levels of student questions as potential contributions to learning, a classroom culture is established in which more student questions emerge which contribute to exploring the curriculum (Beck, 1998).

A third design principle is to establish a sense of shared responsibility for collective knowledge construction. If students only answer their own questions, they most likely will not learn the core curriculum, because their questions often focus only on a subtopic and not on the big picture (Keys, 1998; Polman & Pea, 2001). By sharing questions and answers, students' learning might go beyond their individual questions, because they will collectively explore the whole topic in the classroom. Collective knowledge construction allows students to develop an overview of the key concepts of the topic and allows them to contribute their specific expertise to the benefit of all (e.g. Zhang et al., 2009).

Finally, a fourth design-principle that is found to support effective student questioning, is to visualize progressive inquiry and the process of collective knowledge development. Research shows that student questioning is not static, but is able to progress gradually from basic fact-seeking questioning to more sophisticated wonderment questioning (Hakkarainen, 2003). Essential to support the progressive nature of inquiry is to make students aware of their learning progress, by visualizing how answers raise new questions, and how collective knowledge thus gradually evolves (Zhang et al., 2009). A collective visual platform seems effective to visualize students' prior knowledge as a starting point for collective and progressive knowledge construction. Visualizing collective knowledge also supports teachers in monitoring and assessing student learning outcomes.

Based on these four design principles a principle-based scenario was developed to support teachers in guiding student questioning towards effectivity. The scenario was developed in close collaboration with practitioners in a four-year study consisting of multiple iterations of design, implementation and evaluation (Stokhof et al., 2017b).

4.2.2 Reasons for selecting mind mapping as the visual tool.

Mind mapping was selected as the visual tool in the scenario to guide effective student questioning. Mind maps can be defined as radial structures which allow concepts to be visually organized in organically formed, colored branches (Davies, 2010). Mind mapping was selected because it was expected to visually support all four design principles of the scenario.

First, mind mapping supports identifying a core curriculum within the topic under study, because the structure of a mind map facilitates a hierarchical categorization of domain content into core concepts, subordinate concepts and details or examples (Brinkmann, 2003). Core concepts are placed on the head branches of the mind map, because they represent the top level in the hierarchical structure. Subordinate concepts are placed on sub branches, representing the next level in the conceptual hierarchy. Concepts representing details and examples will be placed on subsequent levels in the mind maps. The core of the curriculum can thus be identified as concepts in, or close to, head- and sub branch level. When teachers construct an *expert mind map* of a topic, they need to consider which concepts are "core" and could represent the conceptual focus, and which are subordinate concepts, details or examples which elaborate and illustrate the core curriculum.

Second, mind mapping supports question generation by visualizing prior knowledge and allowing for divergent questioning. Mind mapping is suitable for visualizing prior knowledge because it supports brainstorming and exchanging information (Shih, Nguyen, Hirano, Redmiles, & Hayes, 2009). Divergent questioning can be evoked because multiple key concepts on the head branches visually support the idea that a topic can be explored from multiple perspectives and interests (Eppler, 2006). Moreover, when questions are linked to the concepts they address, the mind map structure visualizes the variety of questions both in level and in interest. The hierarchical structure of a mind map visualizes if a question is fundamental, addressing a key concept on a head branch, or very specific, exploring a minor detail in a sub-sub branch. Therefore, the structure of a mind map visually supports teachers and students in raising a variety of questions and supports valuing the potential contribution of a question for learning the curriculum.

Third, mind mapping supports a sense of shared responsibility by visualizing students' collective knowledge development (Zhang et al., 2009). All student questions can be visualized in a collective mind map, either as branch or as a hypertext "note" in a digital mind map (Tergan, 2005). Student answers can be integrated in the mind map by adding new information on branches and by restructuring branches. Collective knowledge construction becomes visible when students collaborate to construct a *classroom mind map*, which is elaborated in size and refined in structure. By collaborating on this collective visual platform, students become aware that each and every question contributes to a collective result (e.g. Zhang et al., 2009).

Finally, mind maps can visualize if and to what extent student questioning has been effective and the core curriculum has been attained. Teachers can use mind maps to monitor and assess the individual knowledge development, because constructing a mind map requires both recall of concepts and spatial organization of student's knowledge about topic in a visual structure (D'Antoni, Zipp, & Olson, 2009).

In the process of selecting the most appropriate visual tool to use in the scenario, concept maps had also been considered, because they have many features as visual tool which support collective knowledge construction. However, mind mapping was found to be more suitable than concept mapping for several reasons. First, mind maps were found to be more accessible for the target group (children aged 8 till 12 years old) because the procedures of concept mapping are relatively complex for novice learners, compared to the procedures for constructing mind maps (Eppler, 2006; Merchie & Van Keer, 2012). Second, although concept maps allow teachers to visualize a wide range of relations of different natures, the needs of novice learners, who are just starting to mobilize their prior knowledge of the topic under study, seem well supported by the associative and structuring relations which can be visualized in mind maps (Eppler, 2006; Wetzel, Kester, & Merriënboer, 2011). Third, although Davies (2010) suggested that mind maps are idiosyncratic and hard to understand for outsiders, Shih et al. (2009) showed that the collective use of mind maps was effective for sharing and extending knowledge. Fourth, because of the expected cognitive load of constructing concept maps for primary school children, mind maps were expected to be more valid to guide and assess their emerging knowledge structures.

4.2.3 Measuring curricular objectives in mind maps.

Having developed a principle-based scenario for teacher guidance in a previous study (Stokhof et al., 2017b), the next step in the design-based research project was to identify the impact of the scenario on the learning outcomes for students. The assumption was that the scenario supports effective student questioning. More specifically, the expectation was that by investigating self-raised questions, exchanging answers and constructing collective knowledge, students would attain and elaborate upon the core curriculum. The curricular objectives of the scenario were thus: a) to assimilate and accommodate a core curriculum as a conceptual framework of understanding, b) to assimilate and accommodate new knowledge generated by all classroom questions in this conceptual framework of understanding and c) to refine the structure of their conceptual framework of understanding as indicator of developing expertise (Chi, 2006).

To determine if students attained curricular objectives, three indicators of quality in the student mind maps were operationalized: *similarity* to the core curriculum, *elaboration* of the core curriculum and *quality of structure*. First, an expert mind map represents the conceptual framework of the intended core curriculum which teachers had in mind during preparation, and as such is the point of reference for assessment. Students learn this core curriculum by exploring their prior knowledge and raising SIS questions about it. When student mind maps are compared to an expert mind map, students' recall of the core curriculum can be assessed by counting the number of similar words (McClure, Sonak, & Suen, 1999). Second, teachers also intended students to elaborate upon the core curriculum, but chose not to define how this elaboration was supposed to take shape. Teachers rather chose to allow freedom for students to explore and extend the core curriculum by means of their questions. Therefore, also *added words,* which represent new knowledge generated by student questions, should also be taken into account as learning outcomes. Added words that were related to the topic at hand and logically placed in the conceptual structure of the mind map, were considered to represent the elaboration of the core curriculum. Third, the degree of hierarchy in the mind maps was expected to represent the ability of students to (re)organize existing and new knowledge in several layers (Chi, 2006). Therefore, the degree in which students were able to use multiple levels to structure their knowledge in the mind maps was considered to indicate their degree of mastery of the conceptual structure of the topic.

The hypothesis in this study was that students would gradually internalize the conceptual structure of the core curriculum, and could use it to assimilate and accommodate new knowledge acquired by student questioning in their personal knowledge schemes. The collective raising, exchange and discussion of questions and answers, and visualizing this process of collective knowledge construction in a classroom mind map were expected to help students to learn the whole of the curriculum. Therefore, following research question was formulated: *To what degree do students attain curricular objectives, operationalized as (1) learning a core curriculum, (2) elaborating on this core curriculum, and (3) refining the conceptual structure of their knowledge, when teachers guide student questioning by means of a mind map supported scenario?*

4.3 METHOD

4.3.1 Research method

This study is part of a four-year design-based research project. Design-based research aims to develop a practical solution for a practitioners' problem, as well as, theoretical understandings about the effectiveness of the design principles (Design Based Research Collective, 2003). In design-based research solutions are often developed in a series of studies (Schoenfeld & Conner, 2009). First, design-principles are identified in a review study. Then, a prototype is developed in multiple cycles of design-implementation-evaluation- and redesign, in close collaboration with practitioners (McKenney & Reeves, 2012). Focus of evaluation in these cycles is the perceived relevance, practicality and effectiveness from the perspective of the practitioners (Nieveen, 2009). In other words, the effectiveness of the intervention for the *experienced curriculum* is evaluated (Van den Akker, 2003). Finally, when practitioners perceive the prototype as sufficiently effective, its realized effects on learning outcomes for students can be assessed. Then, the effectiveness of the intervention for *the attained curriculum* is evaluated (cf. Van den Akker, 2003).

Having studied the effectiveness on the experienced curriculum in a previous study (Stokhof et al., 2017b), the focus in this study was on collecting the first evidence on the effectiveness in terms of student learning outcomes. Therefore, this study was set up as a single group pre-posttest design, for its aim is to find out if guidance of student questioning by means of mind mapping will support this group of students in attaining the curricular objectives. However, comparison to non-treatment groups was yet beyond the scope of the objectives in this stage of the development of the scenario.

The use of mind mapping to test students' knowledge of a curriculum is a relatively new approach, and only a few studies have explored mind maps as an assessment instruments (e.g. D'Antoni, Zipp, & Olson, 2009). Therefore, to triangulate results multiple choice knowledge tests about the same curriculum topics were developed in close collaboration with the participating teachers of each school. For each of the key concepts on the head branch level of the expert mindmap, two to three items for the questionnaire were formulated. Similar but different items were constructed for pre- and posttests. For example, in the knowledge test about "Water" two items were related to the key concept "Danger" addressing the sub concept "Flooding". In the pretest item A was asked: "What factor is most likely to cause flooding in the Netherlands?" In the posttest the corresponding item B was included: "Which part of the Netherlands would be flooded when the dikes would break?" In the development of the pre and posttests, teachers were consulted if the items were addressing their intended curriculum. On the basis of their feedback several items were dismissed or reformulated, while some other items were added. The knowledge tests about Water were added as an example in Appendix A.

To check for possible distorting effects in the findings from differences in pupils' grade or gender, these covariates were taken into account in analysis. To check for adherence to the design principles of the scenario and to control for potential differences between various cases, video-recordings of classroom activity and student products were collected.

4.3.2 Population

In total 276 students, aged between 8 and 12 years old, participated. All students came from two primary schools from a suburban area in The Netherlands. Both schools were strongly committed to question-driven learning, and the teachers voluntarily participated in the development and trial of the scenario previously. Students were a non-random sample with previous experience with the scenario.

Students were distributed over 10 classrooms and each classroom was treated as a separate case. In school A, Cases 1 and 2 consisted of combined Grades 5 and 6. In school B, Cases 3-10 were all combined Grades 4-5-6. Students were evenly distributed over grades: 30,2 % in Grade 4, 37,1% in Grade 5 and 32,8 % in Grade 6. The percentage of special care students was below the national average of 9% in each class. All students were moderately skilled mind mappers, being acquainted with the basic mind maps rules and having applied them at least in one or two previous projects. In total 231 students, 117 boys and 114 girls, completed all four tests and only their data was used for analysis.

4.3.3 Treatment

In each school groups of teachers collaboratively designed an *expert mind map* for their science projects in a preparation session. School A chose the topic *The Solar System*, and school B chose the topic *Water*. Teachers first prepared a mind map individually, before discussing with their colleagues which key concepts and subordinate concepts should be in their expert mind map. The collectively designed expert mind map was considered to represent the core curriculum for the chosen topic (Figure 4.1).

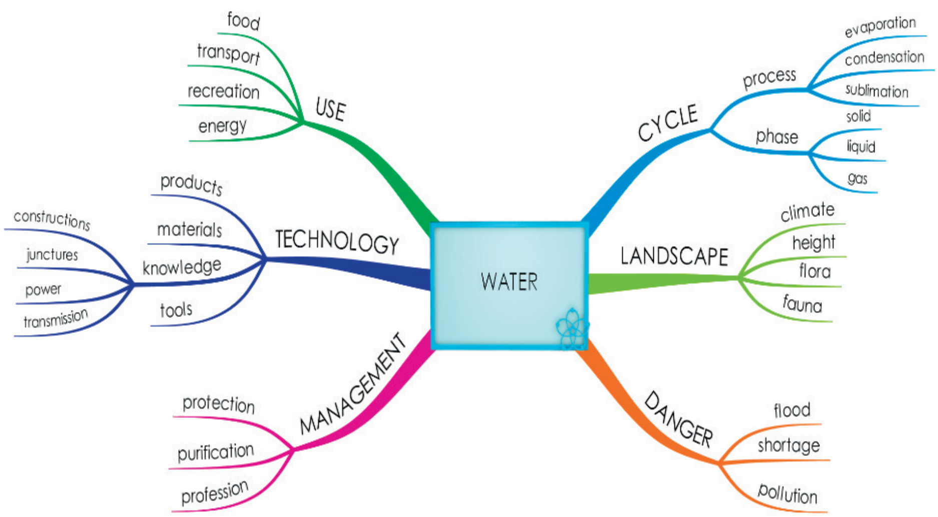
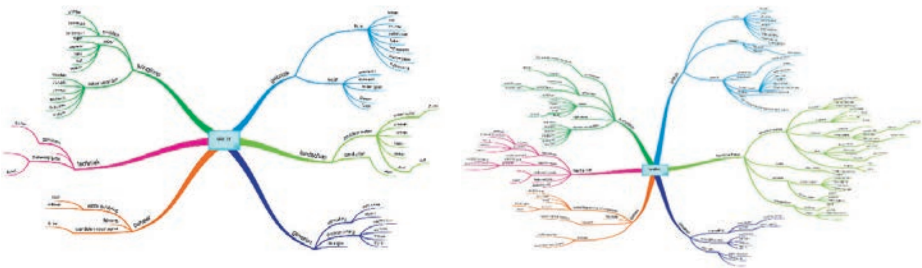


Figure 4.1. Example Expert Mind Map "Water"

In each school students worked for six weeks on their projects. Teachers organized introductions to the projects with the aim to raise students' interest and activate their prior knowledge about the various key concepts. For example, to raise interest for the key concept *Water Cycle* in the "Water" project students conducted a small experiment with steam to make them aware of the processes of evaporation and condensation. The activated prior knowledge on various key concepts was shared in a classroom discussion and in subsequent small group work and then visualized in an initial *classroom mind map* in each case (Figure 4.2).



Initial CMM (week 1)

Final CMM (week 6)

Figure 4.2. Examples of initial and final classroom mind maps (CMM)

Having explored and recorded their collective prior knowledge students were invited to raise questions. Teachers supported question generation by organizing small-group question-brainstorms according to the Question-Formulation Technique (Rothstein & Santana, 2011). In these brainstorms students used the classroom mindmap as question-focus to generate as many questions about the topic as possible, regardless of quality or formulation. By welcoming all questions in this phase, emerging student questioning was fostered and students were encouraged to explore their own wonderings and extend each other's ideas (Stokhof et al., 2017b). The output of this phase was a large repository of initial student questions. Students raised a wide variety of questions about every key concept in the classroom mind map. For example, the question: "How can water rise if you open the tap?" was related to the key concept "Technology", and the question" How can salt water become sweet?" was related to the key concept "Water Cycle". More example questions and their relation to the key concepts can be found in Appendix B.

In the next phase of formulating questions teachers had an active role in discussing these initial questions with students. First, teachers discussed with students: "What is the relevance of the question to the topic? To which (key) concepts are the questions linked in classroom mind map?" The identified links between questions and the classroom mind map were then visualized on the Interactive White Board. Next, each question's potential for learning was discussed. "Does the question's formulation match the questioner's intention? If not, how could it be more accurately rephrased? What kind of knowledge will this question possibly produce? Is the answer already known?" Then possible strategies to investigate questions were discussed. "What kind or resources or actions are needed to find or construct an answer? Might a slightly different formulation make the question more feasible for investigation?" The teacher modeled this with a few examples of student questions. Then students discussed the other questions in small groups reformulating them when deemed appropriate. Finally, teachers and students discussed which questions were most interesting for investigation. When teachers and students had prioritized a selection of the most interesting questions, students could adopt any of those questions to their liking.

Subsequently, students investigated their questions in dyads or individually using the internet and books, interviewing experts, or conducting small experiments. In all cases students were expected to present the answer to their questions in short (two to five minute) presentations to the whole class. During these presentations teachers supported students to relate their new information to the (key)concepts in the classroom mind map, and discussed in class how to the answer contributed to the collective knowledge. In most cases, teachers or students also discussed how to visualize the new information by adding new concepts to the classroom mind map. For example, the answer to question "How can salt water become sweet?" was visualized in the classroom mind map by adding "salt to sweet" and "vapor" (Appendix B). By adding new concepts the classroom mind map gradually expanded during the project (Figure 4.2).

4.3.4 Data Collection

Teachers' expert mind maps, classroom mind maps, students' individual mind maps and multiple choice knowledge tests were collected as primary data to measure the different stages of knowledge construction and individual learning outcomes. The expert mind maps were considered to measure the conceptual structure of the intended curriculum as perceived and constructed by the teachers. The classroom mind maps were considered to measure the collective knowledge construction starting from students' prior knowledge to subsequent stages of added questions and answers. The individual mind maps were considered to measure the degree to which students can recollect, understand and visually represent the conceptual structure of a subject under study.

The individual mind maps were constructed on empty, A3-size, landscape sheets of paper with colored markers and/or pencils. Finally, a multiple choice test, consisting of 18 items distributed over the various key concepts from the expert mind maps, was developed by the researchers to co-measure the individual learning outcomes in an alternative way to the mind maps. Participating teachers at each school were consulted before administering the knowledge tests, to ensure test items would address relevant topics within the intended curriculum, resulting in minor adjustments. Next to the primary data, video-recordings were made of the classroom sessions and informal interviews were held with teachers to control for fidelity of implementation. Furthermore, the students' question worksheets were collected to get an overview of how many questions were raised by the students and which topics were addressed. To comply to the ethical standards for the collection of video materials, all recordings were only made after informed consent of the participants, the data were securely stored in a protected location, and were only used by the researchers for analysis of the data.

To test individual learning outcomes, students made a pretest mind map and knowledge test just after initial introduction and a posttest just after finishing the project. The pre and posttests mind maps were made under similar conditions and students were allowed 30 minutes to complete them. Pre and post knowledge tests were made after the mind map tests, although not in the same session but on the next day in order to minimize test interference.

4.3.5 Analysis

Because the scenario had a principle-based character, it offered opportunity to teachers to adjust the scenario to specific classroom contexts and needs. Therefore, as a first step in the analysis implementation fidelity was established (Mombray, Holter, Teague, & Bybee, 2003). By checking video recordings and product collection it was determined if teachers had adhered to the design principles: a) constructing an expert mind map as representation of the intended core curriculum, b) evoking and recording student prior knowledge about this core curriculum in a classroom mind map, c) elicit student questioning and align it to the classroom mind map, d) encouraging students to investigate their questions and share their answers in class to build collective knowledge with the classroom mind map as a collective point of reference, e) evaluate knowledge development in pre and posttest mind maps.

The video observations and product collection confirmed that all cases adhered to the design principles of the scenario. The only remarkable difference between cases was that Cases 2, 6, 7 and 9 did not elaborate the classroom mind map with new concepts, and did not visualize the progress of the collective knowledge construction. However, the videos showed that the underlying design principle, of the use the classroom mindmap as a point of reference when sharing answers, was adhered to.

To score the individual and classroom mind maps an analysis instrument was developed. Mind maps were scored on three aspects: *similarity* to core curriculum, *elaboration* and *quality of structure*. First, similarity to the core curriculum was determined by counting the number of words which were identical or synonymous to words in the expert mind maps. Degree of similarity was assessed on three levels: on head branch level, on sub branch level and on subsequent levels beyond sub-level termed sub-sub branches. Elaboration of the core curriculum was assessed by counting added words on the three levels. An extra check was made to ensure those words were relevant to the topic and logically placed in the mind map. Quality of structure in the mind maps was analyzed by identifying four levels of conceptual categorization: On the first level words are merely loosely associated with the key concept on the head branch; on the second level words are hierarchically structured on two consecutive branches; on the third level, words are hierarchically structured in three consecutive branches, and on the fourth level words are organized in four (or more) hierarchically structured branches (Figure 4.3).

Level 1: poor Level 2: medium Level 3: high Level 4: excellent

Figure 4.3. Levels of hierarchical structure in mind map

First two raters, who were not part of the research team, were trained to use the mind map analysis instrument. Then the two external raters scored all mind maps. An interrater reliability analysis using the Kappa statistic was performed for 20% of the data to determine consistency of the mind map scoring instrument among the two raters. An average score of $\kappa = .88$ was calculated for all indicators in the instrument, indicating a strong agreement among raters. Dependent paired-sampled T-tests were used to compare means of similar concepts on various levels in individual mind maps. To control for gain scores the Bonferroni correction was applied to prevent Type 1 mistakes, lowering significance levels of $p = .05$ to .01. A linear regression analysis in SPSS was run, to control for any distorting effects of co-variates "gender", "grade" and "case" on the difference between pre and posttests, but no significant effects were found.

To analyze the quality of structure in the individual mind maps first an average score for all branches for each mind map was calculated, before comparing means using a dependent paired-sampled T-test in SPSS. Similarly, the scores on knowledge tests were compared using a dependent paired-sampled T-test. Because observed variance was high in findings of the T-tests, additional analysis was conducted to determine which percentage of the students either a) improved between pre and posttest, b) remained the same or c) regressed between pre and posttest. This was analyzed for the sum of all concepts, for similar words, for added words and for quality of structure.

To identify which factors in guidance might have contributed to progress in student learning outcomes, both questions and classroom mind maps were analyzed. Starting from the assumption that all types of questions contribute to learning (design-principle 2), analysis of students' SIS questions in the worksheets focused on how many questions were raised and whether they addressed the core or the elaborated curriculum. To determine if and how the numbers and focus of questions affected individual and collective learning outcomes, multiple linear regression analysis was run in SPSS™ (version 23).

To analyze the development of collective knowledge, the mind map scoring instrument was used to score both the initial and final versions of the classroom mind maps for similarity, elaboration, and quality of structure. Outcomes for each classroom mind map for each category were listed in a table together with the development of student mind maps for comparison. Multiple linear regression analysis was run in SPSS to determine if and how expanding the classroom mind maps affected development in student mind maps.

4.4 RESULTS

What was the mean effect of the scenario as support for students to attain the curricular objectives?

When comparing the individual pre- and posttest mind maps, Table 4.1 shows that the mean of all *similar words* increases significantly. When zooming in on the distribution of similar words over the various levels, a large effect is observed on head branch level and medium effects are found on sub and sub-sub branch level. Students tended to use more similar words on all levels, but especially on head branch level.

Table 4.1. Similarity to Core Curriculum

	Pre Test		Post Test		T-score	Significance	Effect size
	M	SD	M	SD	*t* (231)	*p*	*r*
Total similar words	7,65	6,29	11, 53	7,47	- 12,04	< .000	.62
Head branch level	3,29	1,89	4,71	1,65	-11,84	< .000	.61
Sub branch level	2,56	2,81	4,00	3,05	- 7,12	< .000	.42
Sub-sub branch level	1,83	3,70	2,87	4,52	- 5,75	< .000	.35

Furthermore, what was the mean effect of the scenario for elaboration of the core curriculum? Table 4.2 shows that the mean of all *added words*, referring to those words which elaborate upon the core curriculum, increased significantly. When zooming in on the three levels in the mindmaps, a significant decrease of added concepts on head branch level was observed, indicating that students tended to use more key concepts from the core curriculum. The increase of added words on sub level approaches insignificance, but elaboration on sub-sub levels was both significant as well as large in effect size. Students seem to have elaborated their mind maps thus primarily by adding words on levels that represent details and examples to the key concepts from the core curriculum.

Table 4.2. Elaboration of Core Curriculum

	Pre Test		Post Test		T-score	Significance	Effect size
	M	SD	M	SD	t(231)	p	r
Total of added words	24,87	13,72	35,88	19,43	- 11,43	< .000	.60
Head branch	1,39	1,47	0,83	1,27	5,51	< .000	.34
Sub branch	13,71	8,47	15,11	8,73	-2,80	< .006	.18
Sub-sub branch	9,77	11,04	19,93	17,20	-11,09	< .000	.59

When analyzing the structure of individual mind maps, Table 4.3 shows that the mean level of hierarchy did increase significantly in the posttest. A large effect size was observed, which indicates students were able to organize their mind maps into more hierarchical structures.

Table 4.3. Level of Hierarchy in Individual Mind Maps

	Pre Test		Post Test		T-score	Significance	Effect size
	M	SD	M	SD	*t* (231)	*p*	*r*
Level of hierarchy	10,40	3,34	13,47	3,53	-12,95	< .000	.64

Because a relatively high standard deviation was found in the T-test, additional analysis was conducted to determine which percentage of the students, either progressed, regressed or retained a status quo between pre and posttests. Table 4.4 shows that approximately 80% of all students succeeded in making progress on all four major variables, however still a substantial percentage of 15% to 18 % regressed between pre and posttests.

Table 4.4. Overview on Student Progression, Regression or Status Quo on Major Mind map Variables

Variables	Percentage for all levels of mind map		
	-	0	+
Total of all concepts	14,2	7,3	78,4%
Total of similar words	14,2	7,3	78,4%
Total of added words	18,1	2,6	79,3%
Quality of structure	15,5	6,9	77,6%

- = regression, 0 = status quo, + = progression

Were the findings, as measured by the mind maps, repeated when a multiple choice knowledge test was used? In both schools knowledge tests were administered addressing either the topic "Solar System" for school A or "Water" for school B. For school B (N = 195) a significant moderate effect size was observed (Table 4.5). However, for school A (N= 38) no significant effects could be reported.

Table 4.5. Multiple Choice Knowledge Test

	Pre Test		Post Test		T-score	Significance	Effect size
	M	SD	M	SD	*t* (231)	*p*	*r*
Knowledge Test A	11,73	2,37	11,39	1,41	0,76	< .455	-
Knowledge Test B	8,93	2,77	10,42	2,45	-6,86	< .000	.44

Having observed significant development in students' individual mind maps on the number of core concepts, detailed elaborations and increased conceptual structure, the collective classroom mind maps and student SIS questions were analyzed in order to see if the significant knowledge gain could be correlated to the number and focus of questions and or the collective use of the mind maps as supported by the scenario. Table 4.6 shows a summary of findings for each case.

As can be observed in Table 4.6, the number of questions varied significantly between cases, ranging from 10 to 25 questions. However, in many cases not all worksheets could be retrieved. Whether students did not use the worksheets, or lost them somewhere in the process, could not be determined. In all cases but one, the number of elaboration questions exceeded the number of questions about core concepts significantly.

Table 4.6. Overview on SIS Questions, Classroom Mind Maps and Student Mind Maps for Each Case

	Student's SIS questions				Development Classroom Mind Maps			Development Student Mind Maps		
	addressing		number		difference initial – final mind maps			% of students who showed progress in		
	Core Curriculum	Elaboration	Total	Missing	Similarity to Core	Elaboration of Core	Quality of structure	Similarity to Core	Elaboration of Core	Quality of structure
Case 1	5	7	12	4	37→64	38→103	2.7→3.7	93.8%	81.2%	87.5%
Case 2*	3	9	12	9	39→39	69→69	4.0→4.0	59.1%	77.8%	68.2%
Case 3	3	12	15	1	24→30	106→134	3.3→4.0	79.2%	83.3%	75.0%
Case 4	4	6	10	12	16→19	88→112	3.3→3.7	74.0%	81.7%	87.0%
Case 5	11	16	25	1	15→19	61→128	3.3→3.5	100%	88.0%	84.0%
Case 6*	3	14	16	8	26→26	26→26	2.8→2.8	73.1%	80.8%	65.4%
Case 7*	5	11	16	2	13→13	89→89	3.2→3.2	60.0%	88.0%	60.0%
Case 8	2	15	17	0	20→20	42→88	2.8→3.8	80.8%	57.7%	73.1%
Case 9*	4	12	16	8	15→15	89→89	2.8→2.8	75.0%	75.0%	79.2%
Case 10	5	3	8	14	15→17	83→103	2.7→2.8	100%	76.2%	81.0%

* = no elaboration of initial CMM observed

Findings in Table 4.6 show that the classroom mind map was expanded in only six cases. Teachers mentioned various explanations for not expanding the mind map in the interviews. Two teachers (Cases 2 and 9) indicated they had not been sufficiently aware that they could have expanded the mind map to visualize growing collective knowledge. Other teachers felt either time-pressured (Case 6), or instructed their students to make personal notes instead of expanding the classroom mind map (Case 7). In those cases where the classroom mind map was expanded, a significant increase in elaboration of the core as well as enhanced quality of structure was observed, next to a slight increase in similarity. These findings suggest that expanding the classroom mind maps resulted primarily in elaboration of the core curriculum and refining its structure.

Multiple regression analysis showed that the question variables (core, elaboration, total number, or missing) did not significantly affect the development of student mind maps. Therefore, we conclude the focus or number of questions did not seem to have a direct effect on progress in student learning outcomes. This implies, that other factors than the student SIS questions may have influenced students' ability to construct their mind maps.

The effects of the question variables on the development of the classroom mind maps could not be calculated in multiple regression analysis, because the assumption of independent errors (Durbin-Watson test) was not met. However, two-tailed Pearson's correlation analysis of the cases in which the mind map were expanded, (n=6), produced some interesting findings (Table 4.7).

Table 4.7. Correlations between Question Variables and Classroom Mind Maps

	Development of Classroom Mind Map		
	Core curriculum	Elaborated curriculum	Quality of structure
	r	*r*	*r*
Number of questions	-	.747*	-
Missing questions	-	-.643*	-.575*
Questions about core concepts	-	.591*	-.628*
Questions about elaborated concepts	-.229*	.609*	.308*

- = non-significant results
* = p = <.000

The only significant (and negative) correlation with development of the core concepts in the classroom mind map were the "elaborating" questions. This might be explained by the relatively large number of elaborating questions, which might have diverted students' attention of learning the core concepts. By contrast, the elaborated curriculum in the classroom mind maps was strongly correlated to all question variables. As expected, when questions were asked, this correlated positively, and when questions were missing negative correlations were observed. More surprising was the finding that both "core" and "elaborating" questions were strongly correlated to the elaborated curriculum. This suggests that also core questions supported the exchange and learning of new concepts. Finally, the quality of structure of the classroom mind map seemed to be positively dependent of the number of elaborating questions and negatively influenced by core questions. Again this finding might be explained by the relatively high number of elaborating questions, in those cases were the quality of structure was increased significantly (for example, Cases 3 and 8). We conclude that asking and exchanging SIS questions was in general positively correlated to building and visualizing collective knowledge.

The effects of the classroom mind map on the development of student mind maps were analyzed using multiple regression. The only significant variable that contributed to progress of all words in student mindmaps, was the increase of elaborated concepts in the classroom mind map (R^2= .045, β=.207, p= .029). In other words, the overall development of student mind maps was enhanced, when new concepts beyond the core curriculum were added to the classroom mind maps. Significant variables for students' progress in similarity to the core curriculum, were both the increase of core concepts (R^2= .171, β=.181, p= .007), as well as, the increase of elaborated concepts (R^2= .171, β=.279, p= .000). This finding suggests that expanding the classroom mind map with elaborated concepts has a larger significant effect on learning the core curriculum, than expanding it with core concepts. Remarkably, none of classroom mind map variables had any significant effect on development of the elaborated curriculum in student mind maps. Apparently, students were able to elaborate their mind maps beyond the core curriculum, regardless if the classroom mind map had been expanded or not. Finally, the quality of structure in student mind maps was positively correlated to the increase of elaborated concepts in the classroom mind map (R^2= .079, β=.399, p= .000), but negatively influenced by the quality of structure in the classroom mind map (R^2= .079, β= -.199, p= .028). This, somewhat unexpected, finding suggests that not the quality of structure of the classroom mind map, but the learning of new concepts supports students in refining their knowledge structures.

4.5 DISCUSSION

The aim of this study was to establish if and to what degree students were able to learn a core curriculum when supported by a scenario to guide effective student questioning. To measure student learning outcomes both individual student mind maps and classroom mind maps were collected. Mind maps tests were triangulated with multiple choice knowledge tests.

Findings on individual learning outcomes showed an increase in similarity and decrease of elaboration in student mind maps on head branch level, which indicates students tended to adhere more to the conceptual structure of the core curriculum as represented in the expert mind map. Elaboration was especially found on sub-sub level, which means students were able to add more details, examples and associations to the core curriculum. Also, a significant higher level of knowledge organization in the mind maps was found. This might be interpreted as a development from novice to expert knowledge about the topic (Chi, 2006). However, not all students progressed when comparing pre and posttests mind maps. Approximately 20% of the students regressed or remained in a status quo.

Another indicator of individual student knowledge advance was the moderate increase measured by the knowledge test. However, this was only significant for school B. One of the possible explanations for non-significance of the knowledge test in school A, is the stage of the curriculum which was measured. The knowledge tests were developed prior to work on the projects in the classrooms. Therefore, the tests were based on the intended curriculum, measuring curriculum content which teachers were expecting to teach (cf. van den Akker, 2003). The mind map pre- and posttests were part of the operational curriculum, thus measuring aspects of the curriculum which were actually investigated, shared, and discussed in class. The development of the classroom mind maps showed that teachers chose to follow an emergent operational curriculum, in which the key concepts were given meaning by students' questions and answers. In this process teachers allowed the curriculum to develop somewhat differently in the classroom, than originally conceived. The knowledge test in school A seems therefore, to have been less aligned to the operational curriculum than previously conceived, and therefore did not measure accurately what students were actually learning.

Findings on collective learning outcomes showed some remarkable differences between cases. Results show that all teachers were able to use mind mapping as a collective platform for linking student questions to the core curriculum. However, not all teachers were aware, able, or willing to visualize the development of collective knowledge. In each case where the classroom mind map was expanded, a large number of new concepts was added to the conceptual structure of a core curriculum. This shows that classroom mind maps can be useful platforms to exchange and visualize new knowledge. When comparing expanded classroom mind maps between cases, however, differences became apparent in the degree of similarity to the core curriculum and quality of structure.

To explain observed differences in individual and collective learning outcomes, student SIS questions were analyzed for number and focus in each case. No significant effects of SIS questions on development in student mind maps were found. However, SIS questioning was significantly correlated with development of the expanded classroom mind maps. These findings suggest, that inquiring into a single personal question will not be sufficient for students to learn the curriculum. Exchanging and discussing questions and answers, however, does contribute to building collective knowledge. A finding which is congruent to the work of, for example, Brown and Campione (1994) and Scardamalia and Bereiter (2006).

The effects of the classroom mind maps on progress in student mind maps were also analyzed. The findings show that expanding the classroom mind map with core and elaborated concepts supported students in learning the core curriculum and refining their knowledge structures. We conclude that visualizing collective knowledge supports individual learning outcomes.

To correctly interpret our findings we would like to point out some of the limitations of the sample. First, we did not have a randomly selected sample but a homogeneous group of students, who all had some previous experience with the scenario. Second, participating classes were taught by motivated teachers, who had contributed to the development of the scenario. Therefore, comparison to non-experienced teachers or classrooms cannot made at this point in time. An implementation study testing the robustness of the scenario in new contexts could contribute to a broader understanding of the effects of the scenario in the future. Finally, although many efforts were undertaken to optimize data collection, 17% of the data was incomplete because of student absence during pre or posttest. Therefore, data from these students could not be used for analysis, which might have influenced our findings.

Two major practical implications for teacher guidance seem to emerge from these findings. First, the findings show that a variety of questions contributed to collective knowledge building. This is congruent to findings of Khanlari, Resendes, Zhu, and Scardamalia (2017), who found there was no significant difference between the positive effects of fact-seeking or of exploratory questions on knowledge building. At the same time, the results demonstrate that the ratio of “missing questions” had strong negative effects on knowledge construction. This suggests that teachers should focus on involving all students in questioning, rather than putting much effort in the formulation of the “right” type of questions. Furthermore, those students who were engaged in answering questions, were more likely to learn the curriculum. This might be explained by the observation, that the student questions which were raised in class seemed to motivate students to learn more about the topic, and made the learning of new content more meaningful because of the connections to own inquiries (cf. Hume, 2001; Keys, 1998; Van Tassel, 2001). Therefore, findings suggest that teachers should not only encourage students to collectively raise questions, but also to make sure that all students are engaged in answering those questions. A second implication concerns the exchange of answers. It seems beneficial for students’ individual learning outcomes to discuss and visualize the construction of collective knowledge, especially when teachers relate students’ answers to the core concepts of the topic under study. This implies that teachers might not only need to discuss answers with their students, but also need to visualize the relations of these answers to the core curriculum.

A theoretical contribution of this study is the finding that visualizing a core curriculum in a mind map supports teachers in balancing freedom for student questioning with attainment of curricular objectives. Visualizing core concepts (or Big Ideas) in a mind map supports teachers to share intellectual control with their students (cf. Mitchell et al., 2017). Providing a conceptual focus by means of a core curriculum, as suggested by Applebee (1996), is operationalized in the scenario as teachers constructing an expert mind map. This focus allows teachers not only to identify the most central curriculum content, but also to construct a conceptual framework that is generative, connecting various concepts with student experiences (Perkins, 1992). When students’ prior knowledge is visualized in a classroom mind map, students can be prompted to raise relevant SIS questions about the core curriculum. Finding answers to these SIS questions can extend and direct development of an emergent curriculum which evolves from this core curriculum (Scardamalia, 2002).

Another contribution to theory might be the development of the mind map research methodology. Originally, mind mapping was primarily intended to support teachers in guiding effective student questioning. However, in this study also a mind map research methodology was developed to evaluate individual and collective learning outcomes. The mind map analysis instrument supported researchers in measuring students’ knowledge construction in an emergent curriculum on several aspects and to compare this to a core curriculum. Of course, mind mapping has, as every research strategy, also its limitations. Mind mapping requires students to recall, organize and visualize their cognitive structures, and although mind mapping seemed suitable for the target group as a visual tool, for some students it still seemed to exceed their cognitive load. This may have limited the validity of some of the findings. However, we consider mind map analysis to be a useful addition to the existing research instruments, since measuring an emergent curriculum with a more traditional multiple-choice instrument proved problematic.

Finally we would like to point out some of the future challenges for guiding effective student questioning. First, results suggest that teachers need time and practice to learn to identify the key concepts of the core curriculum. Classroom mind maps showed that teachers did only partly “cover” the core curriculum beyond head branch level. In interviews teachers explained, that in retrospect many of the selected concepts in their expert mind map on sub and sub-sub level turned out to be less relevant or too abstractly formulated for students. A more careful selection of the concepts in the expert mind map might have enhanced the degree of “coverage” of the core curriculum . This finding is congruent to the experiences of Mitchell et al.(2017), who suggested that framing Big Ideas is not simple and teachers need more support in developing them. Second, it seems necessary to clarify which factors need to be taken into consideration to support visualization of the collective development in mind maps. Considering the positive effects on student learning outcomes, the challenge is to encourage all participating teachers to visualize collective knowledge construction. Finally, we conclude that guiding effective student questioning by a mind map supported scenario enhanced learning outcomes of most students. However, not all students benefited and teachers should be aware that some students might need additional support to internalize the collective knowledge construction. Moreover, although mind mapping as a visual tool seemed suitable for the target group, for some students it still exceeded their cognitive load, and additional scaffolding seems necessary for them.

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APPENDIX A KNOWLEDGE PRE AND POSTTESTS WATER

Key concepts & Sub concepts	Items pretest	Items posttest
Water Cycle Processes I Condensation Evaporation Sublimation	When clouds appear, water changes its state by condensation evaporation melting frost	When it is cold at night you might see in the morning a white layer on the grass. Water has then changed its state by condensation evaporation melting frost
Water Cycle Processes II Condensation Evaporation Sublimation	If you see ice at the sides of an empty freezer, water has changed its state by condensation evaporation melting frost	When you boil water in a pan, water is: condensating evaporating melting frosting
Water Cycle Phases I Solid Fluid Gas	In the case of snow turns water from gas to solid from liquid to solid from solid to liquid from liquid to gas	When there is glazed frost on the road, water turned: from gas to solid from liquid to solid from solid to liquid from liquid to gas
Water Cycle Phases II Solid Fluid Gas	When ice is formed on locks and lakes, water turns: from gas to solid from liquid to solid from solid to liquid from liquid to gas	When it starts to rain water will change: from gas to solid from liquid to solid from solid to liquid from liquid to gas
Landscape Climate	In a tropical climate, it is cold, and there is a lot of precipitation hot, and there is little precipitation hot, and there is a lot of precipitation cold, and there is little precipitation	In a sea climate ensures the sea that it always rains ensures the sea that it almost never rains ensures the sea for large differences in temperature ensures the sea for large differences in temperature
Landscape Height	Water in a river always searches the shortest route to the sea the longest route to the sea the lowest route to the sea the quickest route to the sea	Where does water flow the fastest in the river? in the beginning of the river at the end of the river at the great differences in altitude at the small differences in altitude
Landscape Flora	Which plants grow best in the rainforest? That are the plants that flourish in: a warm and moist environment a cold and moist environment a warm and dry environment a cold and dry environment	Why can grow cacti in the desert? That is because they fourish in a warm and moist environment a cold and moist environment a warm and dry environment a cold and dry environment

Key concepts & Sub concepts	Items pretest	Items posttest
Landscape Fauna	Where do saltwater fish live? IJssel Lake Waal Wadden Sea Meusse	Where do live freshwater fish? North Sea Atlantic Ocean IJssel Lake Wadden Sea
Dangers Flood	Where in the Netherlands is the highest risk of flooding? in Amsterdam in Nijmegen in Utrecht	Which area in the Netherlands would be flooded when the dikes break? De Veluwe Schiphol Limburg
Dangers Pollution	Which water is purified in a water plant? Surface water Rain water Waste water	What is the cleanest water? Surface water Ground water Rain water
Dangers Shortage	What requires the most water in daily use? douche dishwasser toilet washing machine	How can you save the most water in daily use? Drink less washing dishes by hand instead of dishwasher showering shorter wash fewer clothes
Management Protection	How to protect the river country from flooding? by constructing dams by constructing canals by constructing bridges by constructing dikes	Why are the Delta Works built in Zealand? to connect the islands of Zealand together to provide more land for agriculture and housing to provide for recreation and tourism protect the land against flooding
Management Waterways	Why are channels made in the Netherlands? to create opportunity to recreate next to the water to create space for the water to flow away channels are needed for transport on the water	Why is space created for the rivers in the Netherlands? to create opportunity to recreate next to the water than the fish have more space to swim to create space for the water to flow away
Management Profession	What does a skipper do for his job? provides for the transport over water manages the purification of water ensure the safety on the water	What does a lock-keeper do for his job? provides for the transport over water manages the purification of water ensure the safety on the water
Technology Constructions	Where is a dam made for? to determine the water level in the river in order to purify the groundwater in order to pump water out of low-areas to protect against flooding	Where is a pumping station made for? to determine the water level in the river in order to purify the groundwater in order to pump water out of low-areas to protect against flooding
Use Food	What is the recommended amount of water you should drink each day? 0,5 liter 1,5-2 liter 8 liter	How many percent water is in the human body? On average 30 % On average 60 % On average 90%

Key concepts & Sub concepts	Items pretest	Items posttest
Use Food	What food costs the most water to produce? bread vegetables meat fruit	What food costs the least water to produce? tomato cane sugar grain koffie
Use Transport	To which country is most freight transport by inland waterways? Belgium France Germany Engeland	On which river is the most freight transport by inland waterways? Meusse Rhine Vecht IJssel
Technology (open question)	Where does the tap water come from?	Which way do river flow on and why?

APPENDIX B: ALIGNMENT OF STUDENT QUESTIONS TO KEY CONCEPTS AND ADDED CONCEPTS TO CLASSROOM MIND MAP

Key concepts	Student questions	Added concepts to classroom mind map
Water Cycle	How did water originate on earth? Why do seas become salt? How can salt water become sweet? Why is water called water? How quick does water evaporate on the central heating? Does a water in a pond evaporate just as quickly as a water in the tap?	Originate: first water [Melt: Glacier]: ice river Time scale [Evaporate]: salt to sweet, vapor [Weather]: air pressure, dew [fog]: clouds Water vocabulary: bubble, splash, splatter, guggle, fizz
Landscape	How many types of water are there? Where is the moon when it is high or low tide? How do Water Lilies grow? How salt is the Dead Sea?	[Types]: Oceans: Atlantic, Pacific, Indian [Types]: Rivers: Rhine, Waal, Meuse, Danube [Types]: Lakes: natural [Types]: Lakes: artificial: reservoir, dam, Hooverdam- sand mining – local lake [Types]: Seas: Dead- salt, North, Tides- high/low [Types]: Delta- end of- meander Animals: in water: fish, turtles, molluscs, sponges, arthropods; on water: birds, water flea, water strider [Products]: sea weed, algae; fishermen, mussel farmers
Danger	How much water is spilled on a daily basis? How much water does a man use in one year? How many drops of water are on Earth?	[Pollution- Dirty water]: purification plant; plastic: plastic islands Drought: famine, dehydration
Management	Is water healthy when it looks clear? How can be dirty water be purified to drinking water? How many bacteria are in a drop of water? Can you purify ditch water yourself? How many harbours are there in the Netherlands?	[water purification plant]- automatic, biggest Canals- water level Actions- Water Watchers- fund raising
Technology	How can water rise if you open the tap? How can water be put under pressure in the tubing?	[Dams- sluice]: gate; high/low level [Dams]: bridges: sturdy, building, trees [Dams]: Weir Pump: Wind Mills; Pumping station: steam engine, diesel engine Buffer zone Fly boarding
Use	How many percent of your body consists of water? How much water do we use every day? Why do people only drink sweet water?	Nature: water supply: flora- Water Lily; fauna [Self: Swimming]: Waterslide [Self: Water Sports]: rafting, water polo, water battle, surfing, water skiing, synchronous swimming [Self: Drink]: how may liters, each week [Self]: percentage of water in man

Chapter 5

To Adopt or Reject? Testing the Robustness of a Principle-based Scenario for Guiding Effective Student Questioning

Based on:
Stokhof, H. J. M., De Vries, B., Bastiaens, T., & Martens, R. (2018). *To Adopt or reject? Testing the robustness of a scenario for guiding effective student questioning*. Manuscript submitted for publication.

ABSTRACT

Guiding student questioning to become effective for attaining curriculum objectives is a challenge for many teachers. In two previous studies a principle-based scenario was developed in two primary schools to enhance teacher guidance of effective student questioning. This study aims to determine to what extent the scenario for teacher guidance is robust and transferrable to other teachers in different primary school settings. To test its robustness, 15 trainers introduced the scenario in 23 primary schools to 103 teachers. After teachers completed a six-week trial, they indicated in a questionnaire if they were inclined to adopt, adapt, or reject the scenario for future use. Results show that approximately 80% of all teachers would like to adopt the scenario. About 55% of the teachers see opportunities to adapt the scenario to their needs. However, about 20% of the teachers feel not yet able to judge if and how to adapt, having completed only one trial. The conclusion is that most teachers, despite differences in age, gender, grade, experience and school contexts, are willing and able to guide effective student questioning with the help of the scenario. From a theoretical point of view, this study provides further insight in how successful implementation can supported by a principle-based design.

5.1 INTRODUCTION

Asking questions is a basic heuristic for children to explore and to learn about the world (Chouinard, Harris, & Maratsos, 2007). Student questioning is in this study defined as the process in which students generate, formulate, and answer Sincere Information Seeking (SIS) questions, to seek knowledge or to resolve cognitive conflicts (Van der Meij, 1994). Chin and Osborne (2008) show in their review, that asking and answering SIS questions has multiple benefits for teaching and learning (social) science. Moreover, Sikko, Lyngved, and Pepin (2012) found that many teachers are positive about the educational value of student questions and forms of inquiry-based learning.

However, Engel and Randall (2009) report that student questioning is rarely observed in classrooms, while teacher questioning seems to be predominant. According to Penuel and Yarnall (2005) a major challenge for most teachers is to offer the opportunity for student questioning, when confronted with the pressure to cover mandatory domain content. Rop (2002) found that when teachers are faced with such curricular pressures, a spontaneous student question can be easily perceived as a distracting factor in the smooth delivery of a well-devised lesson plan. Teachers seem to struggle to align the freedom, required to elicit student questions, with the structure needed to attain curricular goals (cf. Brown, 1992). Therefore, teachers seem in need of support to guide *effective* student questioning, defined as the degree to which student questions contribute to learning curriculum objectives. To provide this support, a scenario for teacher guidance of effective student questioning was developed and tested for its relevance, ease of use and learner effects in two previous studies (Stokhof, De Vries, Bastiaens, Martens, 2017, 2018)

Ideally, the development of support for teacher guidance takes place in a limited number of trial classrooms. Nieveen (2009) contends that in such small scale studies the relevance, practicality, and effectiveness of a prototype of the educational innovation can be more effectively evaluated and improved. Ultimately, the goal of the development is to make the innovation available to the larger community and therefore the prototype will need to be up scaled at some time. Fullan and St. Germain (2006) claim that to scale up the use of an innovation, its adoptability and adaptability for a wider variety of teachers and school settings needs to be taken in consideration in the design. Moreover, Blumenfeld, Fishman, Krajick, Marx, and Soloway (2000) suggest that to support successful implementation on a wider scale, innovations should not only be aligned to multiple differences in teacher and student characteristics, but also to differences in school culture, curricula, policy and management. Consequently, for a method of guiding effective student questioning to be adopted by teachers in multiple school contexts, it needs to be flexible and adaptable. However, Roschelle, Tatar, Shechtman, and Knudsen (2008) point out that to remain successful in all contexts, the method also needs to retain consistency in its effective components.

Although the scenario for guiding effective student questioning was experienced as relevant, practical and effective in the development schools, it is yet unclear if these benefits will be experienced by other teachers in different settings. The specific contexts of the development schools and teachers' participation in the development process might have contributed to its success, and this might not be transferrable to other settings or to other teachers. Therefore, the aim of this study is to test to what extent of a method for guiding effective student questioning is "robust", defined as the consistency of its benefits when deployed consistently to a variety of teachers, students and settings (Roschelle et al., 2008)

5.2 THEORETICAL FRAMEWORK

5.2.1 Implementation of educational innovations

To be able to study the robustness of an educational innovation, first the concept of implementation needs to be clarified. In this study, implementation of an educational innovation refers to the introduction, trial, and the adoption, rejection or adaptation of a new approach to teaching, which changes the status quo of common classroom practice. Such an innovation is designed to change one or more aspects of teaching such as instruction, (student) interaction, curriculum materials, and or learning environments (Ellsworth, 2000).

To understand the complex nature of implementation, it is important to consider it as a multi-step process rather than an event, as suggested by Nilsen (2015). Rogers (2003) identified five subsequent stages in the implementation process: the *Knowledge, Persuasion, Decision, Implementation and Confirmation* stages. In the Knowledge stage, potential users become aware of the existence of the innovation, gain information how to apply it, and learn about the principles which make the innovation effective. In the Persuasion stage, potential users become more involved with the innovation, seek information about its expected consequences, and develop a general perception about its benefits for their specific circumstances. In the Decision stage, users engage in activities that lead to a choice either to adopt or reject the innovation. Most users, however, will not decide without trying it out on a small scale, in order to determine its usefulness for their own needs and contexts. In the Implementation stage the innovation will be actually put to practice. Finally, in the Confirmation stage the users seek reinforcement in daily practice for the implementation decision made, but may also reverse earlier choices, if the innovation does not meet expectations. This study focuses on the Decision stage in which teachers choose to adopt or reject an innovation after a trial.

5.2.2 Levels of Curriculum Representations

To understand the factors that influence teachers' implementation decisions, an analytic framework is needed that describes the relations between the designers' intentions, the teachers perceptions, the actual use in classrooms, and the outcomes for teachers of the innovation. The model of "*levels of curriculum representations*" of Goodlad (1994) and Van den Akker (2003) provides such a framework. The framework identifies four levels: 1) the *intended* curriculum, 2) the *perceived* curriculum, 3) the *operational* curriculum, and 4) the *realized* curriculum. The intended curriculum consists of the vision, rationale, and mission, which are aspired for the curriculum innovation, and the documentation how the vision can be applied to classroom practice. The perceived curriculum refers to how users understand the intended curriculum. The operational curriculum refers to the actual use of an innovation in the classroom. The realized curriculum refers to the outcomes of the innovation for teachers. Next to these four levels of curricula, Denscombe (1982) also identified the teacher's *hidden* curriculum. The hidden curriculum refers to the sociocultural norms and values in schools that dictate what teachers accept as desirable or acceptable in teaching. The way teachers perceive a curriculum, will therefore be affected by the hidden curriculum.

The perceived curriculum is expected to influence teachers' implementation decisions. Rogers (2003) showed that when an innovation, for example a curriculum, is perceived as beneficial by the end-users, they will be more inclined to adopt it. The quality of the perceived curriculum can be examined using Rogers' (2003) attributes of innovations: *relative advantage, compatibility, trialibility, complexity, and observability.* The scores on these attributes predict the appeal for, and rate of, adoption of innovations. Relative advantage refers to the degree that the proposed innovation is perceived as an improvement of the previous situation. (Rogers, 2003). Compatibility is the degree to which an innovation is perceived as consistent with existing values, past experiences, and needs of potential adopters (Rogers, 2003, p.240). Because the hidden curriculum affects teachers' perceptions of compatibility and relative advantage, this study also measures the hidden curriculum, however, only indirectly. Trialibility is the degree to which users can experiment with the innovation on a limited basis (Rogers, 2003, p.258). Complexity refers to the degree the innovation is perceived as difficult to understand and use (Rogers, 2003, p.257). Finally, observability refers to the degree to which the results of an innovation are visible to others (Rogers, 2003, p.258).

The quality of the operational curriculum can be operationalized as *adherence*, which is the degree to which teachers actually use the innovation in the classroom (Mombray, Holter, Teague, & Bybee, 2003). Cuban (1995) noticed that teachers have considerable autonomy in choosing if and how to teach, and therefore classroom practice can differ substantially from what was intended. Therefore, Mombray et al. (2003) suggest that the degree of adherence to the activities of the innovation is an indicator of its appeal for teachers. Furthermore, Mombray et al. argue that when adherence is high, teachers are more able to give valid judgements on the effectiveness of these activities for their intended objectives.

Finally, also the realized curriculum is likely to influence teachers' implementation decisions. The higher the experienced support for teacher guidance, the more likely it will be that teachers choose to adopt the innovation. Gorozidis and Papaioannou (2014), Jansen in de Wal (2016), and Lam, Cheng, and Choy (2010) showed that teachers' experience of autonomy, relatedness and competence during implementation, correlates strongly with the decision to adopt or to reject an innovation. Therefore, in this study the realized curriculum is operationalized as the teachers' experience of autonomy, relatedness, and competence in guiding student questioning. Relatedness refers to the need to feel belongingness and connectedness to others (Ryan & Deci, 2000). Autonomy is the degree to which an individual perceives an internal locus of causality, or in other words, has the ability to determine his or her personal choices and actions (Ryan & Deci, 2000). Competence refers to experience of "behaviour as effectively enacted" (Niemiec & Ryan, 2009, p. 135).

The framework of curriculum representations will be used in this study to analyze which factors influence teachers' implementation decisions. In this study, the intended curriculum will be the independent variable, because it is the constant factor for all teachers. The perceived, operational, and realized curriculum will be the dependent variables which are likely to influence teachers' implementation decisions. The main hypotheses is that the scenario can be considered "robust" when teachers' implementation decisions are not only positive, but also independent of school context or teacher characteristics. It is expected that teachers' implementation decisions will correlate with findings on the perceived curriculum, the operational curriculum, and the realized curriculum.

5.2.3 Developing a Scenario for Teacher Guidance of Effective Student Questioning

To develop support for teacher guidance of effective student questioning a design-based research approach was applied (McKenney & Reeves, 2014). In previous studies a prototype for guidance was developed, in close collaboration with teachers as the intended end-users. The prototype was tested in multiple cycles of design-implementation-evaluation-redesign, as suggested by Nieveen (1999).

First, the literature was reviewed for teacher guidance of effective student questioning, resulting in identification of four design principles: a) organize collective responsibility for raising and answering questions, b) provide a conceptual focus for questioning, c) acknowledge potential in all types of student questions and, d) visualize the questioning process (Stokhof et al., 2017). Then, these design principles were used as the theoretical underpinnings to develop a principle-based scenario for guidance of effective student questioning in a second study (Stokhof et al., 2018).

The principle-based scenario describes the working principles in five consecutive phases to guide the process of student questioning (Figure 5.1). In the Preparation Phase, teachers design an expert mind map of the topic under study and explore which potential questions could be elicited. In the Introduction Phase, teachers activate students' prior knowledge and students construct a classroom mind map. In the Questioning Phase, the classroom mind map is the prompt for students to raise questions and discuss potential lines of inquiry. In the Construction Phase, students investigate and answer their questions and the learning outcomes are exchanged and visualized in the classroom mind map. In the Evaluation Phase, teachers can use individual and classroom mind maps to evaluate and discuss learning outcomes. Within the structure of this scenario, teachers have ample opportunity to fill it with specific curriculum content and are encouraged to adapt activities to specific classroom needs, as suggested by Zhang, Hong, Scardamalia, Teo, and Morley (2011).

	Phase 1 Preparation	Phase 2 Introduction	Phase 3 Questioning	Phase 4 Knowledge construction	Phase 5 Evaluation
collective responsibility	teacher team	teacher & students	teacher & students	teacher & students	teacher & students
conceptual focus	identify core curriculum	prior knowledge core curriculum	questions about core curriculum	elaboration of core curriculum	reflect on core curriculum
question potential	explore question potential	elicit curiosity	generate & formulate	answer & exchange	reflect on questions
visual tools	design expert mind map	initial classroom mind map	mind map as question focus	elaborate mind map	reflect on mind map

Figure 5.1. Five consecutive phases and design-principles of scenario

In the scenario, each phase consists of *essential activities* and *optional activities* (Appendix A). Essential activities in the scenario are necessary to put design-principles to work in classroom practice. Optional activities might support classroom practice, but are not essential to make design principles operational in class. For example, constructing an expert mind map is considered to be an essential activity, but constructing the expert mind map with colleagues is only an useful option. The degree of adherence to the essential activities, is considered in this study to be an indicator for the appeal of the innovation for teachers.

The relevance, practicality, and effectiveness of the scenario for guiding effective student questioning was tested and improved by multiple cycles of design, implementation, evaluation, and redesign (Stokhof et al., 2017). Only when the scenario had been found to be sufficiently supportive for teacher guidance, the effects on the learning outcomes of students were assessed. In a third study, significant learning gains were identified by comparing the learning goals, as set by teachers in an expert mind map, with student pre- and post-test mind maps (Stokhof et al., 2018). From these findings it was concluded, that the scenario was effective for its main objective: guiding students to attain curricular objectives by means of effective student questioning.

5.2.4 Suitability for scaling-up?

Although previous studies showed that the principle-based scenario was effective in the settings where it was developed, it was not clear, if and to what extent this innovation could be successfully transferred to other teachers in different settings. Multiple studies have shown that the diffusion of an educational innovation beyond its original settings is difficult. For example, Pea and Collins (2008) report that many attempts to scale up classroom innovations to the level of educational systems have been relatively unsuccessful. Therefore, the next step in the development of the scenario is to evaluate the quality of its implementation beyond the original settings. However, the challenge in this study is "not to "sterilize" naturalistic contexts from all confounding variables so the generated theory/model is more valid and reliable" (Barab & Squire, 2004, p.11). Instead, the aim is to test the adoptability and adaptability of the scenario, by researching if it remains useful for teachers in new different school settings.

To prepare the scenario for upscaling, it was designed to be principle-based rather than highly scripted and proceduralized. A scripted proceduralized approach describes very specifically the tasks and activities and the order and form these should take. The aim of this approach is to provide clarity and structure. However, Zhang et al. (2011) suggest that this type of teacher support is not very flexible, does not take differences between educational contexts into consideration, and allows little opportunity for adaptation by the teacher. Furthermore, a highly scripted proceduralized approach seems to limit teacher's experiences of autonomy and competence when working with an educational innovation (Zhang et al., 2011). This influences the success of the implementation, because Jansen in de Wal (2016) proved that a limited experience of autonomy and competence obstructs the adoption of innovations. By contrast, Wen, Looi, and Chen (2012) found that a principle-based approach provides a sequence of pedagogical activities, which supports teachers to translate design-principles into concrete classroom teaching. Zhang et al. (2011) showed that a principle-based design supported teachers in making adaptive decisions to accommodate activities to local contexts, needs, and possibilities. Therefore, it is expected that a principle-based scenario supports the experience of autonomy and competence, which fosters adoption.

5.2.5 School and teachers characteristics as co-variables

Although, the scenario was designed to be adaptable to multiple school contexts and the varying teachers' personal needs, it was hypothesized that specific school and or teacher characteristics might still influence implementation decisions (cf. Ellsworth, 2000). Roschelle et al. (2008) suggest that the innovation can only be considered "robust" when the majority of teachers from different school contexts with various teacher characteristics adopt it. Therefore, several school-context and teacher-characteristics will be included as co-variables in this study (Table 5.1).

Table 5.1. School and Teacher Characteristics as Co-Variables

School Characteristics	Teacher Characteristics
alignment of school vision	gender
organization of social science curriculum	age
curriculum materials	general teaching experience
single or combined-grade classes	experience with mind mapping
size of school team	experience with inquiry-based learning
size of student population	experience with co-designing
percentage special care students	perceived support school management
location: rural or (sub)urban	perceived support trainer
	motivation for student questioning

The school characteristics will be selected as co-variables for several reasons. The alignment of school vision to the use of student questioning in teaching is examined, because the congruence between vision and the innovation is assumed to support implementation (cf. Fullan & St.Germain, 2006). The organization of social science curriculum is taken in consideration, because the scenario is expected be more aligned to project-based curricula than cursory curricula. Also curriculum materials are selected as a co-variable, because the scenario encourages teachers to self-design and adapt materials. For schools that work with a textbooks, the scenario might be less attractive. Another co-variable is the organization of the school in single or combined-grades classes. Teachers in combined-grades might either perceive the scenario as appealing for its adaptivity, or as too complex for the variety in their classroom population. Furthermore, several demographic variables are selected, such as the size of the school team, the size of the student population, the percentage of special care students and the location of the school in either rural or (sub)urban areas.

Furthermore, several teacher characteristics will be selected as co-variables. Gender is taken into consideration, because it is yet unclear if the scenario will be gender-neutral. Age is selected, because it is unclear if the scenario is suitable for all age groups or only for specific age-groups. General teaching experience is included to explore if the scenario will be more appealing for experienced teachers, because of its demands on teacher competencies, or more appealing to novice teachers because they might still be more appreciative of non-traditional ways of teaching. Next to general teaching experience also more specific experience will be examined. Will the degree of experience with mind mapping make adoption more likely, because mind mapping is used in every phase of the scenario? Will the degree of experience with forms of inquiry learning influence the implementation decision, because teachers are more acquainted with the inquiry processes? Will experience in co-designing support adoption, because the scenario encourages teachers to co-design the preparation? Perceived support of school management and of the trainer will be included, because Hargreaves and Fullan (2012) showed that safe and supportive leadership enhanced professional development and implementation of innovations. Finally, teacher motivation to integrate student questioning in their teaching, is expected to be major factor in the implementation decision (Ryan & Deci, 2000).

5.2.6 Research Questions

To research the robustness of the scenario, the following main research question will be addressed: *What is the robustness of a principle-based scenario for guiding effective student questioning?*

To address this main question four sub questions are formulated. First, how do teachers perceive the scenario, operationalized as Rogers' attributes of innovations? Second, to what extent do teachers adhere to the essential and optional activities of the scenario in the operational curriculum? Third, to what extent do teachers experience support for their basic psychological needs in the realized curriculum? And finally, if and to what degree do the (co)variables influence the teachers' implementation decisions?

5.3 METHOD

This study is part of a series of design-based research studies, which aim to support teacher guidance of effective student questioning. In this implementation study the focus is on the robustness of a principle-based scenario for teacher guidance, when introduced in a variety of school contexts.

5.3.1 Procedure

The scenario was introduced in schools that had no prior experience with the scenario. To offer the participating teachers the minimal required support to understand the intended curriculum, 15 trainers were trained by the first author to provide a basic introduction to the scenario. The trainers were all teacher-educators or senior teachers with previous experience in coaching teams of primary school teachers.

Each trainer organized two meetings at the participating schools to introduce the scenario and to help teachers to set up a trial of the scenario. In these meetings, teachers prepared an expert mind map about a social science topic of their choice, prepared an introduction for this topic, brainstormed which potential questions might be elicited in the class, and discussed what kind of guidance these questions may require. After these preparations, teachers trialed the scenario in their own classrooms for about six weeks, each class working three to four hours each week on their projects.

5.3.2 Participants

In total 103 teachers in 23 primary schools in the Netherlands participated in this study. There was no prior selection of schools on specific school characteristics. Any school that had interest in trialing the scenario could participate.

The sample of participating schools can be characterized as heterogeneous. About half the schools are situated in a (sub)urban setting, the remainder can be characterized as rural. The schools vary in size between 70-601 pupils, although most schools are considered medium size: 36% consisting of 101-200 pupils, and 43% of 201-300 pupils. The percentage special care pupils is in 80% of the schools around the national average of 5%. Teacher teams range from 9-43 practitioners, however, most schools teams consist of 9-10 teachers (41%) or 11-20 teachers (42%). In 70% of the participating schools, teachers teach combined-grade classes, often a combination of two or three grades. The social curriculum, for which the scenario is trialed, is organized in 40% of the schools as cursory, and in 60% of the schools as projects. Curriculum materials consist in 70% of the schools of standard textbooks, but in 30% of the schools teachers self-design and self-collect materials. In 92% of the schools, the documents on the school vision seem aligned to the idea that students should be able to raise and investigate self-formulated questions. However, in none of the schools this was common classroom practice yet, when starting the trial.

The sample of participating teachers is also heterogeneous. The ratio between males and females in the sample is 23-77%, which is representative for the teacher population in primary education in the Netherlands. The age of the teachers ranges between 20 and 65, the average age being 40 years. Just over half of the teachers (55%), work four days or more in a week, the other teachers work part-time. Teachers of every grade are well represented in the sample, probably because 70% of them teach classes of combined grades. Their numbers range between 17 participants teaching Grade 1, and 33 teaching Grade 5. Participants have between 1 and 46 years of general teaching experience, the average being 17 years. Many teachers (around 60%) rate themselves as beginners in mind mapping and in guiding forms of Inquiry Based Learning (IBL). A smaller group in the sample (around 30%) perceive themselves as more advanced in mind mapping and guiding IBL. A small majority of teachers rate themselves to be advanced (55%), or even experts (7%) in co-designing projects for their pupils. When introduced to the scenario, almost 95% of teachers felt inspired and supported by the trainer, and felt motivated to trial the scenario. About 80% of the teachers felt sufficiently supported by their school management to do so.

5.3.3 Instruments

The primary source of data in this study is a questionnaire for teachers. The questionnaire consists of five sections: a) teacher characteristics, b) operational curriculum, c) perceived curriculum, d) realized curriculum, and e) implementation choices. The first section focuses on general personal teacher characteristics such as gender, age, working in which grade, and teaching experience, but also collects more specific information on previous experience with inquiry-based learning, mind mapping, and co-designing courses. The second section addresses the operational curriculum, and collects data on which intended activities in the scenario were actually executed in class. The third section of the questionnaire collects data on the perceived curriculum, operationalized as the *Attributes of Innovations* (Rogers, 2003). This section is based on the questionnaires of Moore and Benbasat (1991), Dupagne and Driscoll (2005), and Stachewicz (2011). The items focus on teacher's perception of the relative advantage, compatibility, complexity, trialibility, and observability of the scenario in general, and the use of mind mapping in particular, for each phase. The fourth section of the questionnaire addresses the realized curriculum, and is based upon *Basic Psychological Needs Scale at Work* (Deci et al., 2001). This section inquires how teachers experience support for autonomy, competence, and relatedness when: a) deciding to trial the scenario, b) preparing the scenario, c) working with the scenario in the classroom, and d) reflecting on the learning outcomes of the scenario. In the final section of the questionnaire, teachers are asked which implementation choices they would make when considering future use: Which phases of the scenario would they like to adopt or reject, and which phases would they like to adapt? To give teachers the opportunity to add comments to their responses, open questions are included at the end of each section in the questionnaire.

5.3.4 Data collection

All data was collected during the school year 2016-2017. Table 5.2 provides an overview on all collected data. The questionnaire was distributed digitally by email to all 103 participating teachers. In total 91 teachers completed the questionnaire. Next to the questionnaire also other sources of data were used to triangulate findings. To triangulate self-report on the operational curriculum, teacher and student products were collected for each phase of the scenario such as expert mind maps, classroom mind maps, question worksheets, etc. (Appendix B). To collect data on the school context, existing sources such as school documents and publicly available statistical data on school performance were consulted.

Table 5.2. Data Collection: (co-)Variables, Indicators and Instruments

(co-) variables	Indicators	Instruments	Based upon
School characteristics	Location, vision aligned to student questioning, curriculum materials, curriculum organization, single/combined-grade classes, size teacher team, size student population, percentage special care students.	School documents Consultation of trainers	Ellsworth, 2000; Fullan and St.Germain, 2006
Teacher characteristics	Age, gender, grade, previous experience (general, mind map, IBL and co-design), support school management, support trainer, motivation	Questionnaire	Ellsworth, 2000; Hargreaves and Fullan, 2014; Ryan and Deci, 2000
Perceived curriculum	Relative advantage, compatibility, complexity, trialibility and visible success.	Questionnaire	Rogers, 2003; Stachewitz, 2011
Operational curriculum	Activities performed in the five phases of scenario (Appendix A)	Questionnaire Product collection	Stokhof et al., 2018
Realized curriculum	Experienced relatedness, autonomy and competence.	Questionnaire	Deci et al., 2001
Implementation decision	Teacher’s choice to adopt, adapt or reject	Questionnaire	Rogers, 2003

5.3.5 Analysis

The analysis process consisted of 5 consecutive steps (Figure 5.2). First, the teachers’ implementation decisions were determined for each phase of the scenario. The 7 point-scale of teachers’ choices to adopt or reject, was clustered as follows: Scores 1-3, indicating 0% to 30% likeliness, were interpreted as “rejection”. Score 4, indicating a 50% likeliness, was classified as “in doubt”. The scores 5-7, indicating a 70-100% likeliness, were regarded as a choice for “adoption” or “adaptation”. Then, the percentages of the three implementation decisions were calculated for each Phase.

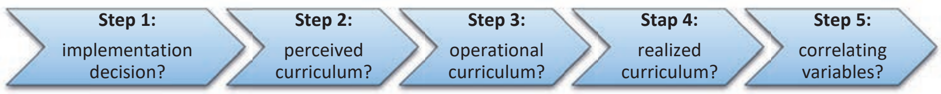

Figure 5.2. Steps in analysis process

To determine an overall score of the implementation decision for the scenario as a whole, the Phases Introduction, Questioning, and Construction were considered to be the essential components of the scenario. This is because these three Phases concern the actual classroom activities to support both student questioning and build collective knowledge about the topic under study. The scores for these three Phases were examined to determine which percentage of the teachers either choose to adopt, to reject, or remained in doubt for the scenario as a whole. If a teacher scored 5 or higher in all three Phases, this was classified as a choice to "adopt". If a teacher scored 3 or lower in all three Phases this was interpreted as "rejection". All intermediate scores were classified as "in doubt".

In the second step, the perceived curriculum was examined, which was operationalized as the attributes of innovations (Rogers, 2003). The questionnaire included two items for each attribute for each phase. Because of the need to calculate sum scores, internal consistency was checked first. Reliability was found to be high for all attributes, ranging between Cronbach's α = .876 and α = .923. Then, sum scores for each attribute in the whole scenario were calculated. To relate the sum scores to the original 7-point Likert scale, a range of corresponding frequencies was calculated by dividing the sum scores by the number of questions. Subsequently, on the basis of this range of frequencies, it was determined which percentage of teachers scored for which attribute on which scale. To identify possible influences of specific phases, the sum of attributes for each phase was also calculated in a similar procedure.

The third step in the analysis was to determine the operational curriculum, operationalized as to what degree teachers adhered to the intended curriculum. Teachers could indicate on dichotomous scale, which activities they had executed in the classroom. In this step, first the frequencies of executed essential activities and optional activities were determined, and then the percentage of adherence was calculated for each activity in each phase of the scenario.

In the fourth step the realized curriculum was analyzed. This was operationalized as the degree to which teachers experienced autonomy, relatedness, and competence when implementing the scenario. For each of the variables, multiple items were included in the questionnaire. Therefore, to ensure internal consistency Cronbach's α was calculated for all three variables. Reliability was found to be sufficient to high: autonomy, 4 items, α = .759, relatedness, 9 items, α = .799, competency, 16 items, α = .764. Subsequently, frequencies were determined for each of these variables, and the distribution of scores over the 7-point scale was calculated for percentages of teachers. Finally, to compare the means and standard deviations between the variables, the outcomes were divided by the number of items in the questionnaire.

In the final step of analysis, the correlations between all variables and co-variables and the implementation decisions were examined. First, significance and size of Spearman's correlations between the implementation decisions and the teacher and school co-variables were calculated in SPSS. Then, also the variables for the perceived, operational, and realized curriculum were included in this correlation analysis.

5.4 RESULTS

5.4.1 Implementation Decisions

Teachers could indicate on a 7-point Likert scale, the likeliness they would adopt or reject the scenario for future use. Table 5.3 shows the findings for adoption in the questionnaire for each of the five phases of the scenario. In the first three Phases, over 80% of the teachers show willingness to adopt the scenario for future use. However, in Phases 4 and 5 the likeliness to adopt decreases slightly and more teachers are in doubt or do not expect to continue working with (parts of) the scenario. The overall implementation decision, combining the scores for Phases 2, 3, and 4, indicate that a majority of teachers show willingness to adopt the scenario as a whole for future use.

Table 5.3. Decision to Adopt or Reject Scenario

Phase	Decision: reject (0-30% likely to adopt)	Decision: in doubt (50% likely to adopt)	Decision: adopt (70%- 100% likely to adopt)
1: preparation	4,8%	14.2%	81.0%
2: introduction	7.1%	9.5%	83.4%
3: questioning	3.6%	9.5%	86.9%
4: construction	10.7%	13.1%	76.2%
5: evaluation	14.3%	15.5%	70.2%
Overall score	**10.7%**	**13.1%**	**76.2%**

(Table 5.4). A small majority of teachers, around 55%, indicate they would like to adapt the scenario in future use. From the teachers' comments to the open questions it is understood, that teachers have different arguments for their decision to adapt or not. Some teachers find the scenario fitted to their needs, and feel no urgency to adapt it. Other teachers see various opportunities to fit the scenario to their needs, or express willingness to experiment with variations on the scenario. Other teachers indicate they are just getting acquainted with the scenario, and feel they are not yet able to determine if and how to adapt the scenario.

Table 5.4. Decision to Adapt Scenario

Phase	Decision: don't adapt (0 – 30% likely to adapt)	Decision: in doubt (50% likely to adapt)	Decision: adapt (70% - 100% likely to adapt)
1: preparation	23.8%	19.0%	57.1%
2: introduction	23.8%	21.4%	54.8%
3: questioning	27.4%	17.9%	54.7%
4: construction	27.4%	14.3%	58.3%
5: evaluation	26.3%	15.5%	58.3%
Overall score	**27.4%**	**21.4%**	**51,2%**

5.4.2 The Perceived Curriculum

The perceived curriculum is operationalized as the five attributes of innovation (Rogers 2003). As Figure 5.3 shows, 87% of the teachers perceive the attributes of the scenario generally as "somewhat positive" (score 5 = 26%), "positive" (score 6 = 46%) or "very positive" (score 7 = 15%). The most positive attribute is Relative Advantage (M= 5.43, SE= .85), followed by Compatibility (M=5.36, SE= .88). Complexity is perceived as the least positive attribute, although the average score is still positive: 4.87 (SE= .84)

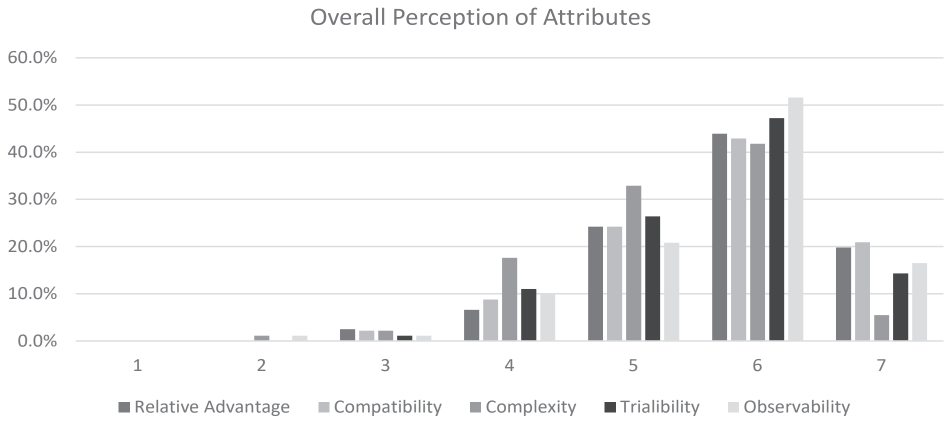

Figure 5.3. Teachers' overall perception of attributes

The distribution of scores on perception of attributes in the various Phases, is shown in Figure 5.4. More teachers are more positive about the Preparation (Phase 1 = 92.3%), the Introduction (Phase 2 = 85.7%), and the Questioning (Phase 3 = 81.3%), than about Construction (Phase 4 = 74.7%), or Evaluation (Phase 5 = 74.7%). Highest appreciated are Preparation (Phase 1: M= 5.56, SE= .83) and Introduction (Phase 2: M= 5.87, SE= .99). The Evaluation Phase is appreciated least (Phase 5: M= 4.85. SE= 1.02).

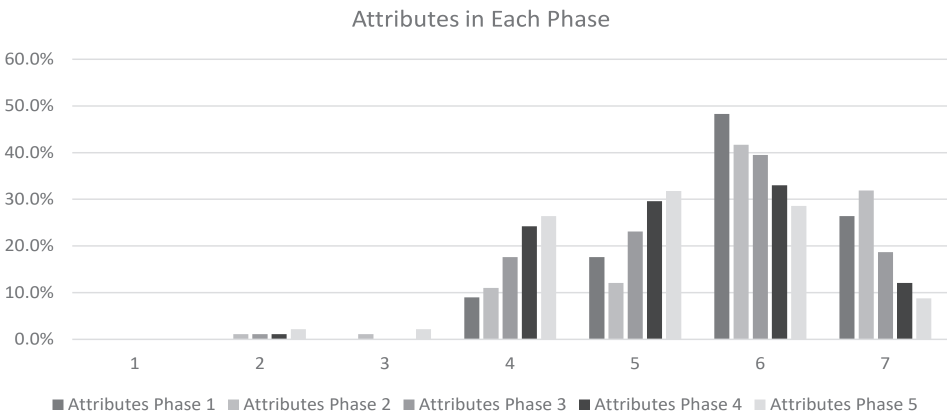

Figure 5.4. Teachers' perception of attributes in each phase

5.4.3 The Operational Curriculum

To check if teachers' implementation decisions are influenced by the extent to which the scenario is implemented in the classrooms, both the use of essential and optional activities were monitored (Table 5.5). In the first three Phases of Preparation, Introduction, and Questioning, the teachers' adherence to the essential activities is found to be high. However, in the Construction and Evaluation Phases the adherence percentages decrease significantly. Teachers' comments to the open questions show that some teachers felt somewhat time-pressured in the course of activities, and were either not able, or choose not to engage in all activities in the last two Phases of the scenario.

Table 5.5. Adherence to Essential and Optional Activities

Essential Activities		Optional Activities	
Phase 1 Preparation			
Construct expert mind map	83%	Collectively construct expert mind map	76%
Prepare introduction	93%	Collectively prepare introduction	73%
Prepare prompts for questioning	91%	Collectively prepare prompts	69%
Phase 2 Introduction			
Elicit prior knowledge	87%	Think of individual prior knowledge	80%
Exchange prior knowledge	88%	Note prior knowledge	68%
Structure classroom mind map	80%		
Phase 3 Questioning			
Question brainstorm	81%	Discuss question quality	73%
Select questions together with pupils	79%	Discuss question formulation	67%
		Allow students to adopt questions	51%
Phase 4 Construction			
Link questions to mind map	64%	Discuss links between questions	50%
Expand mind map with answers	51%	Collective responsibility for mind map	58%
		Expand mind map with teacher lessons	46%
Phase 5 Evaluation			
Discuss development mind map	57%	Individual pretest mind map	18%
		Small group pretest mind map	41%
		Individual posttest mind map	16%
		Small group posttest mind map	24%
		Compare pre and post mind map	20%
		Alternatives to discuss development	78%

5.4.4 The Realized Curriculum

The realized curriculum is operationalized as the extent to which the scenario supported teachers' feelings of autonomy, relatedness, and competence. Table 5.6 shows how the average scores of participants are distributed over the 7-point Likert scale. Teachers experience in general positive levels of autonomy (M=5.91, SE=. 84), of relatedness (M=5.61, SE= .66), and of competence (M= 5.36, SE= .60).

Table 5.6. Results of the Realized Curriculum

Variables	Percentages of average scores						
	1	2	3	4	5	6	7
Autonomy (4 items)	0%	0%	0%	6%	10.7%	32.1%	51.2%
Relatedness (9 items)	0%	0%	0%	4.8%	13.1%	57.6%	25.0%
Competence (16 items)	0%	0%	0%	2.4%	23.8%	63.1%	10.7%
Sum score self-determination variables (29 items)	0%	0%	0%	2.4%	13.1%	66.6%	17.9%

5.4.5 Correlations with the Implementation Decision

To check for possible influences of the various variables on teachers' implementation decisions, correlations were calculated .

Table 5.7. Variables that Correlate with Teachers' Implementation Decisions

	Variables	Correlates with	
		Adopt	Adapt
Operational curriculum	Essential activities Phase 2 (Introduction)	.309**	-
	Essential activities Phase 4 (Construction)	.479**	-
	Essential activities Phase 5 (Evaluation)	.497**	-
Perceived curriculum	Relative Advantage	.567**	-
	Compatibility	.626**	-
	Complexity	.437**	-
	Trialibility	.543**	-
	Observability	.528**	-
Experienced curriculum	Autonomy	.571**	.234*
	Relatedness	.497**	-
	Competence	.576**	-
	SDT-(all)	.624**	-
School characteristics	Size school team	.223*	-
	Single or combined-grades classes	-.250*	-
Teacher characteristics	Support school management	.294**	-
	Support trainer	.462**	
	Motivation for student questioning	.625**	-

- = non-significant, * = *p* <.005, **= *p* <.001

Table 5.7 shows that of the operational curriculum only the essential activities of Phases 2, 4, and 5 correlate positively with adoption. This finding suggests, that those teachers who did adhere to these essential activities, are more inclined to adopt the scenario in the Introduction, Construction, and Evaluation Phases. Regarding the perceived curriculum, the attributes of the scenario are not only generally appreciated as positive, but also significantly influence the decision to adopt. Especially, compatibility, relative advantage, and trialibility are strongly correlated with adoption. Similarly, high scores in the realized curriculum, concerning teachers' feelings of autonomy, relatedness, and competence, are significantly correlated to adoption. The only significant, and relatively weak, correlation with adaptation is autonomy.

Only two of the eight school variables have a small influence on adoption: the size of school team and teaching in combined-grades classes. Just three teacher variables are correlated with adoption: perceived support of the school management, perceived support of the trainer, and teacher motivation. This suggests that most differences in teacher and school variables do not influence the decision to adopt the scenario.

5.5 DISCUSSION

The general inclination of teachers to adopt, suggests that the scenario addresses teachers' needs in guiding effective student questioning. The finding that many differences in school and teacher variables do not correlate with the implementation decision, shows that the scenario is appealing to a variety of teachers in various school contexts, thus meeting the criteria for robustness (cf. Roschelle et al., 2008). We conclude, therefore, that the scenario is "robust" and transferable beyond the original settings in which it was developed.

When examining the differences in implementation between the phases of the scenario, an interesting pattern emerges. The relative low rates of adoption for the phases of Construction and Evaluation (Phases 4 and 5 of the scenario) seem congruent to the gradual decrease in the appreciation of, and adherence to, the essential activities in these phases. Apparently, in the course of the scenario it became gradually more difficult for some teachers to integrate its features in their teaching. Remarkably, adherence to the essential activities in Phase 4 and 5 correlates positively with the teachers' decision to adopt the scenario. This suggests that those teachers, who did use mind mapping to build collective knowledge and to evaluate knowledge development, are more inclined to adopt it for future use. This is desirable, because in a previous study was found that especially visualizing and discussing collective knowledge construction enhanced student learning outcomes (Stokhof et al., 2018). However, further studies are needed to explore, how to encourage a considerable minority of teachers to experience the potential of mind mapping for guiding knowledge construction and evaluation in Phases 4 and 5.

A possible explanation for the high rate of adoption and degree of robustness is that the scenario addresses a felt need of teachers. As Kotter (1995) and Marino (2011) suggested, many successful educational innovations start with the willingness of the participants to change the current status quo. The high levels of motivation of participants to trial the scenario, demonstrated teachers' general willingness to experiment with a more student-centered approach to teaching. The high level of adoption could be interpreted as that teachers had experienced a high level of success in trialing the scenario, and were confident that future use would continue to support them in guiding effective student questioning (cf. Abrami, Poulsen, & Chambers, 2004).

Another factor which may have contributed to adoption and robustness, was that the scenario was designed a priori for upscaling. The primary strategy to enhance upscaling was to choose a principle-based approach, which could offer both autonomy and competency support (cf. Van Loon, 2013). Teacher's competency is supported in the scenario by offering structure in consecutive phases of guidance, based upon design-principles. Autonomy is enhanced by providing opportunity for teachers to adjust the scenario to their personal needs and classroom contexts. Moreover, the scenario also supports relatedness between teachers, because the collaborative activities in Preparation Phase are highly appreciated (Stokhof et al., 2018). By taking these basic psychological needs of autonomy, relatedness, and competence into account in the design, the likeliness of adoption seems to be supported (Gorozidis & Papaioannou, 2014; Jansen in de Wal, 2016; Lam et al., 2010). Furthermore, when working with the scenario, the teachers are expected to be active and critical participants. In the scenario, teachers develop their own projects, make critical choices in curriculum content, and implement classroom activities themselves. This is congruent to the suggestion of Richter and Allert (2017), who advocate that to support the development process, teachers should have an active and critical role. As Samoff, Dembélé, and Molapi Sebatane (2013) found, scaling up is enhanced when participants have the opportunity to adapt or redesign specific elements of the innovation, and local ownership is thus encouraged. If other principle-based designs will similarly support the implementation of educational innovations, however, will require further study.

Findings on teachers' decisions to adapt, however, seem ambiguous. The open questions reveal that teachers had different arguments whether to adapt or not. The decision not to adapt, seems to be based on two arguments. Either, teachers appreciate the scenario as it is, or teachers feel not yet able to decide, if and how the scenario should be adapted. Even when teachers feel able to decide to adapt, this can mean two things. On the hand, a few teachers indicate that certain flaws need to be addressed. On the other hand, other teachers see opportunities to adapt the scenario to align it to their specific needs. Therefore, these differences in interpretation are probably the cause, that only autonomy is significantly correlated with adaptation. It appears, the more teachers feel in control to adapt, the more likely they are to choose for some form of adaptation.

To correctly interpret these conclusions, we would like to point out some of the limitations of this study. First of all, the participants were a self-selected sample of teachers from interested schools, not an ad-random sample of all schools. Findings about adoption of scenario are, therefore, only representative for schools and teachers who are interested in integrating student questioning in their classroom practice. Nevertheless, in the course of this study, we found multiple schools and their teachers interested to trial the scenario in the near future. Second, this study describes teachers' perceptions, actions, and experiences of the scenario in the Decision phase of implementation. Further use of the scenario beyond this phase could not yet be monitored. However, the teachers' intention to adopt was considered a predictor for future use, as suggested by theory of Reasoned Action Approach (Fishbein & Ajzen, 2010).

To summarize our conclusions, the findings show that most teachers in our sample are highly motivated to encourage student questioning, but experience a need for support. The principle-based scenario for teacher guidance of effective student questioning appears not only to address this need, but also proves to be "robust": Various teachers in different school contexts experience the scenario as an appealing and useful support for guiding students to raise SIS questions, which contribute to attaining curriculum objectives. The principle-based character of the scenario offers both the structure for teacher guidance, as well as, freedom for teachers to align this guidance to personal needs and local circumstances. Furthermore, this study contributes to the body of knowledge about the complex, and very often underestimated, process of adoption of educational innovations.

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APPENDIX A

Essential and optional activities in the operational curriculum

Phase	Essential activities	Optional activities
Preparation	Construct expert mind map Prepare introduction Prepare prompts for questioning	Collectively construct expert mind map Collectively prepare introduction Collectively prepare prompts
Introduction	Elicit prior knowledge Exchange prior knowledge Structure classroom mind map	Think of individual prior knowledge Note prior knowledge
Questioning	Question brainstorm Select questions together with pupils	Discuss question quality Discuss question formulation Allow students to adopt questions
Construction	Link questions to mind map Expand mind map with answers	Discuss links between questions Collective responsibility for mind map Expand mind map with teacher lessons
Evaluation	Discuss development mind map	Individual (or group) pretest mind map Individual (or group) posttest mind map Compare pre and post mind map Alternatives to discuss development

APPENDIX B

Phases, activities and collected products in operational curriculum

Activities in the scenario		Collected products
Phase 1 Preparation	Prepare expert mind map	Expert mindmap
	Prepare introduction to key concepts	Introduction materials
	Prepare for potential questions	Question brainstorm
Phase 2 Introduction	Introduction	Introduction materials
	Inventory of associations	Field of words
	Individual mind map	Mind maps
	Cluster concepts	Word clusters
	Form branches	Classroom mind map
	Construct classroom mind map	Classroom mind map
Phase 3 Questioning	Question brainstorm	Lists of questions
	Exchange questions	Annotated questions
	Evaluate questions	Annotated questions
	Select questions	Question work-sheets- Classroom mind map
	Reformulate questions	Question work-sheets
	Adopt questions	Question work-sheets- Classroom mind map
Phase 4 Knowledge construction	Predict answers	Question work-sheets
	Select sources	Question work-sheets
	Find/construct answers	Question work-sheets
	Present answers	Question work-sheets - various materials
	Discuss answers	-
	Adapt classroom mind map	Versions of classroom mind map
	Discuss progressive inquiry	Follow-up questions
Phase 5 Evaluation	Evaluate classroom mind map	Versions of classroom mind map
	Evaluate individual mind map	Pre and post student mind maps

Chapter 6

General conclusions and discussion

6.1 RECAPITULATION OF STUDIES AND FINDINGS

Asking questions is an important strategy for students to learn curriculum content. Self-raised questions help students to probe and deepen their understanding, and to explore new fields of interest. Moreover, opportunity for student questioning enhances intrinsic motivation, fosters the development of metacognitive skills, and supports critical thinking and creativity. Teachers, however, seem to find it difficult to encourage student questioning in class due to curricular pressures. They face the practical problem of aligning authentic student questioning with curricular objectives. In other words, teachers seek support to guide student questions to become effective for learning the curriculum.

In this thesis the following general research question is addressed: *How to support teachers to guide effective student questioning*? Four studies were conducted to answer this question: a validation study, a development study, an effectiveness study, and an implementation study.

The *validation* study in Chapter 2 aimed to identify the design principles for developing a practical solution for teacher guidance of effective student questioning. The following research question was raised in this systematic qualitative literature review: *Which emergent themes with respect to guiding effective student questioning in primary school classrooms can be derived from the literature?*

To answer the research question, a data set of 36 articles was collected, using both study and report characteristics as inclusion criteria. All studies are peer-reviewed empirical reports on teacher guidance of student questioning in primary education published since 1990. The data was analyzed in a three-by-three matrix, relating three phases of questioning (generating, formulating, and answering) to three perspectives on teacher guidance (teacher characteristics, instructional moves, and organization of student support).

The findings show that teachers combine a variety of teaching strategies to successfully guide the three phases of questioning. Four design-principles emerged, when analyzing the patterns how teachers effectively guide student questioning: (1) creating a supportive classroom culture for question generation by acknowledging potential in all questions, (2) defining a conceptual focus by means of a core curriculum, (3) establishing a sense of shared responsibility to collectively cover a core curriculum and organize peer-collaboration accordingly, and (4) visualizing student questioning and its relation to the curriculum.

The *development* study in Chapter 3 aimed to develop a practical solution based on these design principles as well as theoretical understanding if and how this might offer support to teacher guidance of effective student questioning. The research question was: *What is the relevance, practicality, and effectiveness of digital mind mapping in a principle-based scenario for guiding effective student questioning?*

To answer the research question, a multiple case design study was conducted. In this study, the four design principles were operationalized as a principle-based scenario for teacher guidance of effective student questioning consisting of five phases, in which digital mind mapping was used as a tool for preparation, introduction, questioning, knowledge construction and evaluation. The scenario was developed and tested in nine classrooms by 12 teachers. Video-recordings of classroom activities and interviews with teachers were collected as the primary data. Analysis focused on fidelity of structure, operationalized as adherence to and duration of the five phases, and fidelity of process, operationalized as the relevance, practicality, and effectiveness of the scenario for guiding effective student questioning as perceived by the teachers.

The findings on structure fidelity show that teachers adhered to most of the phases and activities of the scenario within set time-constraints, with the exception of evaluating learning outcomes with students (Phase 5). The findings on process fidelity confirmed that in general 10 teachers perceived the scenario as relevant, practical, and effective for guiding effective student questioning. However, two teachers were critical of the practicality and effectiveness of mind mapping in the Knowledge Construction and Evaluation phases, because they noticed some students had difficulty with extending the classroom mind map and constructing their own mind maps. Overall, it was concluded from the results that the scenario generally supported most teachers in guiding effective student questioning.

The aim of the *effectiveness* study in Chapter 4 was to determine if and how the scenario affected intended learning outcomes operationalized as students attaining core curricular goals by raising and exploring SIS questions. The research question was formulated as: *To what degree do students attain curricular objectives, operationalized as (a) learning a core curriculum, (b) elaborating on this core curriculum, and (c) refining the conceptual structure of their knowledge, when teachers guide student questioning by means of a mind map supported scenario?*

In two schools 10 teachers and their 273 students worked with the scenario on a self-chosen social science topic for a six week period. The teachers' expert mind map about the topic was assumed to represent the intended core curriculum. Pre and posttest student mind maps, teachers' expert mind maps, and classroom mind maps were collected as the primary data. To measure the attainment of the core curriculum the students individual and collective classroom mind maps were compared to the teachers' expert mind maps. To triangulate the outcomes on the mind map tests, also a conventional pre and posttest multiple choice knowledge test was administered.

The findings show that approximately 80% of the student mind maps improve in three ways: increased similarity of the core concepts mentioned, elaboration on the core concepts, and improved quality of structure. About 7% of the mind maps remain in a status quo, and 15% of the mind maps show a decrease in either similarity, elaboration, or quality of structure. At the same time, a significant moderate positive effect is observed in the results of the multiple choice knowledge test. Analysis of the SIS questions posed by the students shows no direct effect on individual learning outcomes, but does relate significantly to the development of collective knowledge in the classroom mind maps: The development of classroom mind maps significantly affects the attainment of core concepts and quality of structure in the student mind maps. Based on these results, it was concluded that the scenario is effective in terms of attaining curricular objectives for most students.

The aim of the *implementation* study in Chapter 5 was to determine to what extent the principle-based scenario for guiding effective student questioning would be “robust” when implemented in new settings. Robustness is defined as the consistency of benefits, when deployed to a variety of teachers, students, and settings. The following main research question was raised: *What is the robustness of the principle-based scenario for guiding effective student questioning?*

To answer this question, the scenario was introduced to 103 teachers in 23 schools. Schools differed from each other in terms of their organization of the curriculum, organization of grades, curriculum materials, and demographical characteristics. Teachers differed in terms of their age, gender, experience, work factor, and teaching grade. All teachers trialed the scenario in their classrooms for a six-week period. A questionnaire was administered, which measured the teachers’ implementation decisions, use of activities of the scenario, perceived attributes of the scenario, experienced autonomy, competence, and relatedness, and various teacher and school characteristics. Findings on classroom activities and school variables were triangulated with product collection (such as mind maps, question sheets and student products) and school documents.

The findings show that the teachers perceive the scenario as relatively advantageous and compatible with existing practices. Working with the scenario supports teachers’ feelings of autonomy, competence, and relatedness. Approximately 80% of all teachers would like to adopt the scenario for future use. About 55% of those teachers see opportunities to further adapt the scenario to their needs. Adherence to all phases of the scenario enhances the likeliness for adoption. Further exploration of the data shows that most school and teacher characteristics do not correlate with the decision to adopt or reject. The conclusion is, therefore, that most teachers, despite differences in age, gender, grade, experience and school contexts, are willing and able to guide effective student questioning with the help of the scenario.

6.2 FROM RESULTS TO MAIN CONCLUSION

Based on the results of the four studies the main question of this thesis can be answered: *How to support teachers to guide effective student questioning*? We conclude that the principle-based scenario generally supports teacher guidance during all phases of the questioning process. In the Preparation phase, the scenario supports teachers to identify a core curriculum and to explore possible perspectives for student questioning.

Teachers can successfully construct expert mind maps in their teams, which prepares them for guiding effective student questioning in class. In the Introduction phase, the construction of a classroom mind map supports teachers to make students aware of their prior knowledge about the core curriculum. Teachers report that the collaborative effort of discussing, organizing, and visualizing prior knowledge in class fosters student engagement and elicits students' interest and curiosity. In the Questioning phase, teachers can use the classroom mind maps as an effective tool for question generation in small groups. The output of such a question brainstorm triggers the whole class discussion about the relevance, potential, and investigability of the generated questions, and brings about a process of refining the formulation of the questions. In the Construction phase, the scenario supports teachers to guide collective knowledge construction, by visualizing how the questions are related to the core curriculum, and how the answers elaborate the collective prior knowledge. However, although in all observed classrooms students' questions were related to the classroom mind map, the visualization of answers in the classroom mind map in the Knowledge Construction phase was not observed in all cases. The degree to which teachers share the responsibility for continuously adapting and extending the classroom mind map with students, turns out to be one important predictor for the visualization of knowledge construction. Finally, the scenario supports teachers in the Evaluation phase to monitor and evaluate students' learning process and learning outcomes. The collective classroom mind map supports teachers to discuss the potential of questions and answers as contributions to the understanding of the core curriculum. However, the possibility to use individual mind maps as indicators of individual learning outcomes was not fully realized. All findings were replicated beyond the original development context. The implementation study shows that the scenario for guiding effective student questioning is generally perceived as appealing and supportive by various teachers in different school contexts.

Each of the four design principles in the scenario seems to have contributed to the success of the scenario. The principle of question potential was successfully operationalized in the Preparation, Introduction and Questioning phases of the scenario. By exploring potential questions during preparation, teachers felt more able to anticipate on student questioning and to provide interesting prompts to introduce the topic. In the Introduction and Questioning phases the teachers were able to elicit curiosity and trigger a wide variety of student questions which contributed to exploring and understanding the core curriculum. However, the potential of continuous student questioning, in which answers lead to new questions and progressive inquiry, was only occasionally observed in the Knowledge Construction phase. Furthermore, not all teachers systematically reflected with their students on the potential and impact of student questioning in the Evaluation phase.

The principle of conceptual focus, operationalized as a core curriculum, was found to be successful in all phases. The conceptual focus supported teachers both in seeking the potential for learning in student questioning, as well as, offering the support for those questions to contribute to curricular objectives and evaluating learning outcomes. These first two principles together, seem to have laid a firm base for effective student questioning by supporting a classroom culture in which questions were welcomed and deemed relevant to the curriculum.

To a lesser extent did the scenario support collective responsibility successfully. The principle of collective responsibility was mainly found to be effectively operationalized in the Preparation, Introduction, and Questioning phases, resulting in high engagement of both teachers and students. In these three phases all participants in all cases were actively involved in working towards a shared goal, either being an expert mind map, a classroom mind map or a set of interesting questions. In the Knowledge Construction phase, however, collective responsibility was not observed in all cases. A few teachers found ways how to organize knowledge building as a collective objective, but in other cases the students' focus was mainly on answering their own questions and less on learning together. And although in some cases the collective knowledge construction was discussed in the Evaluation phase, the scenario did not provide sufficient stimulus to do so in all cases.

Finally, the principle of visual support operationalized as using mind maps, shows a similar pattern: The use of mind maps was successful in the first three phases of the scenario. The expert mind map provided teachers with a useful conceptual focus. The classroom mind map visualized the students' prior knowledge and seemed effective as a question focus for raising relevant student questions. However, more mixed effects were observed in the phases of Knowledge Construction and Evaluation. In the classes where teachers managed to organize collective responsibility for learning, the classroom mind map seemed to be an useful platform for knowledge exchange. In other classes the classroom mind map was not elaborated with the students' answers, and as a result the collective knowledge construction was not visualized. The support of the mind map for monitoring and evaluating knowledge development was therefore not realized in all cases. This suggests that in the last two phases of the scenario the operationalization of the principles of collective responsibility, visual support, and question potential might need further attention.

6.3 LIMITATIONS

To correctly interpret the findings presented here, we would like to reflect on some of the limitations of our studies. Some of the limitations we discuss here, concern the educational context in which the studies were conducted. Other limitations are related to methodological choices.

First of all, it is important to consider the cultural and educational context in which the four studies were conducted. All studies were situated in The Netherlands, and therefore its prevailing social and cultural norms in primary schools may have influenced findings. For example, the encouragement of assertiveness and individual development of students is commonly held in high esteem in The Netherlands (Harkness et al., 2007). This social norm supports the idea of students asking their own questions as socially desirable. In other countries where the adaptation to social status quo is considered important and social adaptiveness is highly valued, student questioning might be interpreted as less desirable, as it may be perceived as challenging teacher's authority in the classroom (Tan & Seah, 2011). When intending to transfer this innovation to other educational contexts in other countries, one should therefore account for differences in national and school culture, as well as seek for opportunity to promote the idea of student questioning as being socially desirable. A second factor in the cultural context, which might have influenced findings, is the open character of the educational objectives for primary education in the Netherlands. The Dutch government assumes responsibility for the quality of education and has set general objectives, the so called *Core Objectives*, for all school subjects on all levels of education (Ministry of Education, Culture and Science, 2006). However, unlike for example England, there is no National Curriculum which prescribes in detail how teachers should attain these objectives (Oates, 2011). Therefore, Dutch teachers have considerable professional autonomy in teaching subjects in ways they deem best for their students (Ehren, Leeuw, & Scheerens, 2005). When teachers had to construct an expert mindmap, their concerns about coverage of the Core Objectives were easily addressed. As a result, teachers felt free to experiment with student questions as a method of teaching and learning the curriculum.

A second limitation concerns the use of participatory design in our studies. Participatory design was chosen because the problem addressed in this thesis was essentially a practitioner's concern. In participatory design the end users of innovations are actively involved in the design, implementation, and evaluation of the solution. The merit of participatory design is that the developed curriculum materials are more likely to be experienced as valid and feasible by the end users (Penuel & Gallagher, 2009). By developing solutions in close collaboration with the end users the ecological validity of the outcomes can be enhanced (Nieveen, 2009). The involvement of teachers had multiple advantages for the development of the scenario, such as receiving instant feedback and suggestions to further improve the practicality of the scenario.

Participatory design, however, also proved to have limitations when specific expertise of the participants was called upon. Although participatory design supports ecological validity, primary school teachers are trained to be generalists and not domain experts. Therefore it can be challenging for them to define a core curriculum. This became apparent in the effectiveness study (Chapter 4), which showed that indeed some of the teachers struggled to identify the conceptual framework of the core curriculum. These teachers seemed to need additional support to acquire the in-depth conceptual knowledge that was necessary to shift from working with textbooks to a more conceptual approach of curriculum content. Janssen (2017) even suggests that it should be academic domain experts and not teachers who prepare such conceptual frameworks. Probably, domain experts may have provided more in-depth expert mind maps, but this might have violated the ecological validity of the expert mind map as a teacher tool to guide student mind mapping. Another point to consider is, that making the expert mind maps themselves, enhanced the teachers' feelings of autonomy and competence and consequently their willingness to trial the scenario. Therefore, we suggest that follow-up research into the development of the scenario should seek to balance the required expert conceptual knowledge with the advantages of participatory design.

Finally, we would like to point out a limitation concerning the ability of the respondents to draw mind maps. In this thesis mind maps were used to measure learning outcomes in terms of students' knowledge construction. We measured this by analyzing the mind maps for their similarity to a core curriculum, elaboration of the core curriculum, and the quality of the conceptual structure in the mind maps. Students' capacity to draw mind maps is a necessary precondition for this type of measurement. Therefore, all respondents had at least one previous training in making mind maps, before making pre- and posttests. Most students were able to make mind maps representing their prior knowledge and posttest knowledge. However, many teachers reported that in their classes one to three students struggled with drawing the mind maps, because of the demand on visual-spatial capacities and fine motor skills. Although the effects of this limitation to our measurements is expected to be equal for both the pre- and post-test, and not of influence on the general findings on knowledge improvements, it is expected that for these students no valid measurements could be made of their factual knowledge development. We suggest that future research should take the ability of students to draw mind maps into consideration as a co-variable in measurements as well as seek for additional instruments to triangulate findings of the mind map tests.

6.4 THEORETICAL AND PRACTICAL IMPLICATIONS

In this section we discuss some of theoretical and practical implications which might be derived from our findings.

6.4.1 Theoretical Implications

Van der Meij (1994) describes questioning as a process that consists of three phases: (a) generating, (b) formulating, (c) answering questions (e.g.). In the generating phase the learner becomes aware of the need or possibility to ask a question, triggered internally by a cognitive disequilibrium or externally by events or phenomena evoking a state of perplexity or an inquisitive stance. In the formulating phase, the learner tries to verbalize his or her perplexity by formulating a question (verbal coding) and can choose to express it in a social setting (social editing) urging them to physically pose the question.

In the third phase of answering, the learner consults available resources, and processes acquired information in order to construct an answer to his or her question. Many studies have shown that pupils experience great difficulty with verbal coding when formulating questions (e.g. Allison & Shrigley, 1986; Tan & Seah, 2011). Therefore, the verbal coding of questions has had much attention within the literature, based upon the assumption that correct phrasing of questions is a precondition for starting inquiry (cf. Janssen, 2002). However, although various strategies have been proven successful in eliciting certain types of higher order questions, for example question-stems (King, 1991, 1992), Jirout and Klahr (2011) show that training does not necessarily support students to frame their curiosity into a question. As Neber (2008) reports, pupils might learn the mechanics of formulating a grammatically correct question, but might not yet know how to frame their personal interests in meaningful SIS questions.

How does this present research relate to this overall picture of student questioning? Our findings from teacher and student interviews and classroom observations suggest that to gain momentum for meaningful SIS questioning, it might be necessary to invest time in a divergent phase of question formulation in which students first formulate a large number of potential questions, before discussing and comparing the meaning and impact of the way these questions are formulated. In the beginning of our research many teachers paid attention to the correct phrasing of students' questions in the formulation phase immediately. Teachers discussed the quality of question formulations with the students, often in one-to one conversations, and urged students to reformulate their fact-seeking questions as higher-order questions. This was time-consuming for teachers, and appeared to be counterproductive as many students lost the motivation for their initial questions and came up with simple correctly phrased questions they already knew the answers to. Our findings indicate, that too much emphasis on the technical skill of question formulation stifles the students' inquisitive stance, which confirms findings of Neber (2008) and Jirout and Klahr (2011).

Therefore, an alternative strategy to guide question formulation was introduced in the scenario based on the findings of Beck (1998), Busching and Slesinger (1995), Rothstein and Santana (2011), and Van Tassel (2001), who emphasize collective generation and evaluation of questions by students and teachers. In this strategy teachers first encourage students to generate questions in small groups. In our case, triggered by concepts in the classroom mind map, students formulate multiple questions about various sub topics, and build upon each other's questions by association. The brainstorm produces a large repository of potentially interesting lower and higher order questions from which students select the most interesting questions. Subsequently, the relevance, feasibility, and learning potential of this selection of questions is discussed in class. Our findings support the assumption that collective formulation of questions is an effective strategy to support students in framing their curiosity in questions, as earlier identified by Van Tassel (2001). A divergent step in the phase of question formulation, encouraged students to explore their interests within the conceptual framework of the classroom mind map together. By not focusing on the correct wording of the questions or the consequences for subsequent inquiry, as suggested by Rothstein and Santana (2011) and Scardamalia and Bereiter (1992), students felt free to brainstorm and motivated to formulate questions. The divergent strategy also addressed teachers' practical challenges in guiding question formulation, as were identified by Keys (1998) and Nardone and Lee (2011), such as time-consuming mediation of question formulation and lack of quality control.

In sum, the present research suggests that it is effective to first encourage students to formulate multiple potential questions in a question brainstorm, before raising attention to the quality of the formulation. This seems to improve both students' intrinsic motivation for questioning as well as the question quality, in terms of seeking new knowledge. As a consequence, the formulating phase in the three phase model of the process of questioning (Van der Meij (1994), could be refined by adding two sub phases: "*formulating potential questions*" and "*correctly phrasing questions*".

A second theoretical implication of this finding is that the *collective* process of generating, formulating, and selecting questions supports the design principle of "question potential". The collaborative effort in the scenario affords welcoming both lower and higher order questions as potential building blocks for collective knowledge construction. Many students have the tendency to first raise basic information-seeking questions (De Vries, Van der Meij, & Lazonder, 2008). In a collective setting these fact-seeking questions do not need to be reformulated into higher order questions, but can be utilized as building blocks to start constructing higher-order collective knowledge. By acknowledging the value of the initial fact-seeking questions teachers foster and sustain student motivation for questioning. Furthermore, the results show that this variety in questions does not obstruct collective knowledge building. This is congruent to findings of Khanlari, Resendes, Zhu, and Scardamalia (2017), who report there is no significant difference between the positive effects of fact-seeking or of exploratory questions on knowledge building.

A third theoretical implication of the present study concerns the effects of core curricula on teachers' use of curriculum materials. Several studies suggest that many primary school teachers tend to adopt a *textbook-oriented approach* in teaching social sciences (Notté, Van der Schoot, & Hemker, 2011; Sunal & Sunal, 2008; Zhao & Hoge, 2005). A textbook-oriented approach to teaching can be defined, according to Hintz (2014) and Nicol and Crespo (2006), as teachers considering the textbook as the authority for what and how to teach, adhering to its routines and structures, and making few or no adaptations to lessons, tasks, problems, and exercises in the textbook. The popularity of textbooks among teachers can be explained by the multiple advantages they have for teaching, such as the pre-selection of curriculum content, the provision of practice activities, and the structure they offer in classroom routines (cf. Crawford, 2002; Richards, 2001; Kaufman et al. 2002). However, a strict textbook-oriented approach seems to be disadvantageous for teaching. Richards (2001) and Nicol and Crespo

(2006) find that not all textbooks have the quality that teachers require. Textbooks often focus on facts and topics rather than on developing conceptual understanding, and are not easily adaptable to differences between students and contexts. Focusing on the textbooks can deskill teachers, according to Ben-Peretz (1990) and Hintz (2014), because teachers who use textbooks tend to stick to the textbook routines, even when they know and would want to use more engaging and adaptive ways of teaching.

An alternative to a textbook-oriented approach is the *concept-based approach* to teaching, defined by Milligan and Wood (2010) as teachers using concepts as tools to select what and how to teach. Concepts are operationalized in this definition as the "general ideas that can organize facts and topics into higher level generalizations" (cf. Erickson, 2002, p.5). The main advantage of the concept-based approach seems to be that it supports teachers to filter the huge amount of available information about a topic and to identify the most important ideas to teach (Milligan & Wood, 2010). As Grossman and Thompson (2008) observe, a conceptual approach supports teachers to consider their textbooks as just one of the useful resources for their teaching and not as the authority how and what to teach. Furthermore, critically examining curriculum content from a conceptual perspective, helps teachers to adapt content and instruction to their students' needs and interests. Milligan and Wood (2010) find that a concept-based approach supports teachers to avoid the pitfall of a curriculum that is a "a mile wide and an inch deep" (p.4), and to teach more effectively for conceptual understanding. Frampton (2009) reports that students in a concept-based condition performed significantly higher on motivational and cognitive tests than a control group.

One of the design principles of the scenario for guiding effective student questioning is to choose a conceptual focus for questioning. In the scenario the concept-based approach is operationalized for teachers by collectively constructing an expert mind map to identify a core curriculum, and in subsequent phases constructing a classroom mind map with their students. When collectively making an expert mind map teachers discuss the potential and the core of the topic with each other, which helps them to learn how to critically examine curriculum content (cf. Ben-Peretz, 1990). The findings in our studies support the idea that the scenario successfully supports a concept-based approach, and therefore encourages teachers to let go of strict adherence to curriculum materials such as the textbook. The scenario both strengthened teachers' conceptual overview on the topic as well as enhanced teachers' self-confidence to change their teaching practice. Teachers reported that identifying core concepts in the mind map enhanced both their domain knowledge and their conceptual understanding. Our studies show that making an expert mind map reinforced teachers' confidence that they could guide students to construct their classroom mind map. Teachers also reported that the conceptual overview in a classroom mind map supported them to encourage student questions, for teachers felt more confident they could align these questions to the curricular objectives. Furthermore, most teachers claimed that because of the conceptual overview in the mind map, they felt no longer the need to rely on the textbooks or other curriculum materials for their instructional decisions. This is in line with the findings of, amongst others, Gudmundsdottir and Shulman (1987) and Nilsson (2008) who also report that acquiring a conceptual overview is essential to support teachers' self-confidence as well as to encourage them to elaborate their teaching repertoire. Furthermore, our findings resemble also those of Diaz (2011) and Zeegers (2002) who show that both the teacher's degree of domain knowledge and their self-confidence correlate with the likeliness that teachers will adapt curriculum materials to their students' needs. Summarized, we conclude that our findings confirm the assumption that a concept-based approach to teaching supports teachers to rise above a textbook-oriented teaching style.

6.4.2 Practical Implications

Next to theoretical implications, we would like to point out some practical implications of our research. Our findings show a principle based scenario is a relevant, practical, and effective scaffold for guiding effective student questioning. Teachers appreciate that the scenario addresses the relevant concerns they have when trying to embed student questioning in their teaching. This perceived relevance seems to be supported because teachers feel that "urgent needs" are addressed (Kotter, 1995) and experience "a relative advantage" over the current situation (Rogers, 2003). The scenario is especially valued for the support in finding the balance between allowing freedom for student questioning and providing structure to attain curriculum objectives. But how can the success of the present research be explained, and be used to invite and to support teachers to start local design and implementation experiments with student questioning?

An important factor for the practical success of the research for teachers seems to be the principle-based nature of the scenario. The participating teachers perceived the scenario as a practical tool in several aspects. The principle-based nature of the scenario provided on the one hand the structure and the support for a sequence of concrete classroom activities, which teachers highly appreciated. On the other hand, the principle-based nature of the scenario provided teachers with opportunities to trial and experiment with the scenario, and adapt it to their local settings and preferences. Because the scenario is not a scripted lesson plan but a flexible method to design, implement, and evaluate their teaching, the scenario serves as a starting point for further exploration and adaptation. Working with the scenario encouraged the teachers to become aware of their roles as (re)designers, who make their own instructional decisions, as suggested by Doyle and Rosemartin (2012). Our findings show that teachers highly valued this acknowledgement of their professional autonomy. We conclude that a principle-based scenario, as an example of open-ended curriculum materials, empowers teachers in their role as (co-re-)designers. This is important, because as Brown (2009) observes: "When teachers use curriculum materials they are always engaging in design

–whether or not they intend to do so" (p. 23). Therefore, to improve teaching practices teachers should be supported in developing their pedagogical design capacity (Brown, 2009; cf. De Vries, Schouwenaars, & Stokhof, 2017). This thesis seems to support the idea that educational innovations can be successfully based on open-ended design products. These open-ended design products could both support the development of teacher competency as well as encourage teacher autonomy by affording (re)design decisions. A principle-based scenario is an example of such an open-ended design product, providing both the structure of design principles and the freedom to select and adapt content and classroom activities (e.g. Oost, De Vries, & Van Schee, 2016).

A second factor which contributed to the practical success of the research seems to be the collective professionalization of the teachers. In the Preparation phase of the scenario teachers collaborated to identify the core curriculum in an expert mind map, to explore potential student questions, and to organize concrete classroom activities to elicit both prior knowledge and guide student questioning. Multiple benefits of this teacher collaboration were observed. When making the expert mind map teachers tried to identify a core curriculum, teachers soon discovered they had different perspectives on the topic. By exchanging and discussing their perceptions of the curriculum objectives, teachers developed a shared conceptual focus and deepened their understanding about the topic. Similar finding were reported by Borko (2004), who shows that by collectively (re)designing curriculum materials, teachers may not only produce relevant curriculum materials, but also deepen and challenge each other's understanding of the intended curriculum. The collective preparation of the scenario also supported the exchange of ideas on how to organize concrete classroom activities. To support this second step, several examples were provided of how the operational curriculum might look like, but teachers were also encouraged to explore and acknowledge different but equal pathways to bring the principles to practice (cf. Ben-Peretz, 1990; Grossman & Thompson, 2008). The teachers reported that discussing the various possibilities to enact the scenario in the classroom supported them to make the most appropriate decisions for their own practice. Moreover, the preparation activities resembled many of the intended teaching activities, so that teachers could practice and experience them with colleagues before taking them to the classroom. Teachers emphasized that this form of preparation lowered the threshold to actually put their ideas into practice, because they were more aware what to expect and more conscious how to act. This resembles the findings of Boschman, McKenney, Pieters, and Voogt (2016), who report that anticipating and practicing classroom activities triggers specific pedagogical content knowledge. Smith, Blake, Kelly, Gray, and McKie (2013) coin this specific knowledge as *pedagogical process knowledge*, operationalized as the knowledge and skills that teachers need to support their pupils in developing certain ways of working and thinking. It seems that the open-ended nature of the principle-based scenario encourages teachers to articulate and discuss the required pedagogical process knowledge to put it to practice. Finally, findings show that the collective endeavor of preparation raises team spirit and teachers' engagement for using the scenario in classroom practice. Discussing what and how to teach was an interesting and enjoyable experience, in which they mutually inspired each other to take new steps in their teaching.

We conclude that when teachers are asked in a collaborative setting to articulate, specify, and discuss how they would like to use curriculum materials in their classroom practice, this supports the operational curriculum, as suggested by Hintz (2014). A practical implication of this study is therefore that collective professionalization elicits pedagogical discussions which in turn enhances the development of pedagogical process knowledge necessary for successful implementation.

To summarize the practical implications of this thesis, three factors can be identified that support future educational innovations to gain momentum in classroom practice. First, teachers should be made aware of their role of designers, who can re- or co- design their curriculum materials and adapt them to local settings and preferences. Second, teachers should be provided with open-ended curriculum materials, such as principle-based scenarios, that empower them in their roles as designers. Finally, the most effective method to professionalize teachers in working with these open-ended curriculum materials seems to be to engage teachers in a collaborative process of (re)design, implementation, and evaluation.

6.5 FUTURE CHALLENGES

In drawing conclusions from the studies conducted, future challenges were observed that could inform further research on the guidance of effective student questioning. The first challenge we observed is encouraging ongoing student questioning (cf. progressive inquiry, Hakkarainen, 1998; Hakkarainen & Sintonen, 2002). Although the scenario effectively supported knowledge building, students rarely engaged in ongoing inquiry. Why was this the case? Our observations suggest that first of all students need time to shift to an inquisitive stance, and become more proficient in asking progressive kinds of questions. Other research confirms that deeper questioning demands that students get more familiar with the topic first (Martinello, 1998; Pedrosa de Jesus, Teixeira-Dias, & Watts, 2003; Watts, Gould, & Alsop, 1997). In some studies which did report progressive inquiry, students worked for several months to a year on their projects (e.g. Hakkarainen, 2003; Lehrer, Carpenter, Schauble, & Putz, 2000; Zhang, Scardamalia, Lamon, Messina, & Reeve, 2007). In our studies students only worked on 6 week projects, which might be too short to bring progressive inquiry about. Future research on effective student questioning might therefore explicitly take into account the timing and duration of student questioning.

Furthermore, the lack of depth in the conceptual focus chosen by teachers might have inhibited progressive inquiry. Although we found that the design principle of conceptual focus was helping, other researchers suggest that there is more to it than just defining core concepts. For instance, Donham (2010) en Taba (1962) suggested that besides having a conceptual focus, students' attention should also be shifted to a conceptual rather than factual level, so that students inquire concepts instead of facts, which in turn encourages in-depth analysis. Likewise, Janssen (2017) suggests that what is needed is a domain-specific question structure which introduces important perspectives to students with which they can observe reality and analyze information. Translating these suggestions to the scenario and the design principle of conceptual focus, would mean we not only support teachers in defining core concepts, but in defining core perspectives to question the concepts as well. For example, a topic like "dinosaurs" could be more profoundly studied, if students do not just collect names and features of various types of dinosaurs, but explore the topic from the perspectives of evolution, extinction, or form-function. Analysis of the participating teachers' expert mind maps showed that selecting the most effective conceptual focus was already a challenge. We reckon that adding domain specific perspectives is another challenge to address.

The second future challenge we observed is organizing assessment for learning. Assessment for learning aims to make students aware of their current progress in learning and provide feed-forward for future learning activities (cf. Black & Wiliam, 1998). It seems logical not only to offer students opportunity to pursue their own interests by raising self-formulated questions, but also to offer them opportunity to monitor and evaluate their learning progress (Nicol & Macfarlane-Dick, 2006). In the scenario, the evaluation phase was designed to support teachers to evaluate learning processes and outcomes with their students. However, organizing assessment for learning is a major challenge for many teachers (cf. Sluijsmans & Kneyber, 2016). And indeed, the implementation study shows a remarkable contrast between the perceived advantage of the evaluation phase, and its actual use. Considering the potential benefits of providing task-related and process-related feedback on student learning (Hattie & Timperley, 2007; Pintrich & De Groot, 1990), it seems important to further explore in more detail how teachers could be supported to formatively assess learning processes and outcomes with their students. Most teachers considered evaluation as a final activity, which is often skipped because of time-constraints at the end of a project. Therefore, teachers might need support in seeking other opportunities for formative evaluation earlier in their projects. For example, students could rate each other's questions for relevance, learning potential, and investigability and suggest possible improvements in Phase 3, provide feedback about progress made in Phase 4, and teachers could evaluate the progress of collective knowledge at several moments.

Finally, the third challenge we observed is the transfer of our findings to other educational levels. Encouraging student questioning seems important for students of all ages. In secondary education and vocational training, for example, demotivation of students for school subjects is a matter of growing concern (Peetsma, Hascher, Van der Veen, & Roede, 2005). A major cause for this seems to be the limited opportunities for students' self-determination (Reeve, 2009). By encouraging student questioning, students would get more opportunity to explore subjects from their personal interest. Similarly, in tertiary education, students are expected to behave as active self-regulated learners, who articulate their personal learning needs (Nicol & Mcfarlane-Dick, 2006). Moreover, the competence to be self-regulative is deemed important in their later professions. Therefore, vocational and tertiary education might need to prepare students to raise relevant questions and engage in self-regulated progressive inquiry. At the same time, the curriculum is often fixed and determined by standardized tests and assessments (Birenbaum, 2003). As a result, many tertiary students seem to act as passive consumers of curriculum content instead of active self-regulated learners.

Although student questioning seems as important in secondary, vocational, and tertiary education, their curricula and teachers seem to face similar challenges. This raises the question if and how the scenario could address teachers' concerns in all educational sectors, taken in consideration that there are striking differences between sectors in the levels of learning content, learning goals, curriculum structures, and school organizations.

6.6 CONCLUDING REMARKS

This study aimed to develop an effective solution to a practical problem experienced by practitioners in primary education. We intended to support teachers to find a balance between providing structure and offering freedom in their guidance of student questioning. In our search to find this balance, we felt much inspired and supported by the works of the pioneers in the field. In our studies we could build on ideas as: Applebee's "Curriculum as conversation" (1996), Brown and Campione's "Knowledge building in community of learners" (1994), Scardamalia and Bereiter's work on "Big ideas" and "Knowledge Forum" (2006), and Shodell's "Question-driven classroom" (1995).

We hope our findings will open up opportunities for teachers to integrate more student questioning in education. To make this shift in education happen, teachers themselves have a pivotal role. More emphasis on student questioning, does not mean that teacher guidance will become less important. Our findings show that guidance of effective student questioning is not "laissez faire", in which teachers become obsolete. Rather, when guiding student questioning the teacher's role in the classroom becomes even more important and challenging. It requires teachers, who can identify the relevant core curriculum, elicit students' prior knowledge about it, support question generation and formulation, and guide question to answers which contribute to collective knowledge construction. Moreover, in the process teachers should also be able to gradually release control of classroom activities, and transfer responsibility for knowledge construction to students.

Considering these required competencies, we expect that most present primary school teachers will need some form of professionalization to guide effective student questioning. When developing the scenario, we found that even the most experienced of our participating in-service teachers were not yet fully prepared for working with the scenario. This was not surprising finding, for guiding effective student questioning was not the type of teaching they had been prepared for in Teacher's College. Therefore, we suggest that pre-service teacher education should prepare future teachers to develop required competencies. Most effective might perhaps be when in-service and pre-service teachers collaborate in their professional development to guide effective student questioning. In our studies we found that some of pre-service teachers, which were introduced to working with the scenario at Teachers College, trialed it in their classroom practice at their professional development schools. Moreover, most of these pre-service teachers persuaded, by their initiative, their mentors (all experienced in-service teachers) to trial the scenario together. Exploratory evaluation of these trials showed that both pre- and in-service teachers not only found the collective trial challenging and inspiring, but also both perceived this as a significant contribution to their professional development.

We conclude that guidance of effective student questioning has a lot of potential for teaching and learning, which suggests a need for progressive inquiry into the topic, for this study offers only a few answers while raising much more new questions.

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List of tables and figures

TABLES

FIGURES

Summary

This thesis reports on research about the challenge for primary school teachers to embed students' Sincere Information Seeking (SIS) questions in their teaching. SIS questions, defined as self-raised questions to enlarge knowledge or resolve cognitive conflict, have multiple benefits for both learning and teaching. They foster students' intrinsic motivation, enhance their inquisitive stance, promote development of cognitive and metacognitive skills, and support self-directed knowledge construction. Teachers can use student questioning to diagnose students' level of understanding, monitor their students' lines of reasoning, enhance inquiry, and evoke critical reflection.

Unfortunately, student SIS questioning is scarce in many classrooms, and much of its potential for learning and teaching remains unused. Teachers have a pivotal role in changing this classroom practice. However, teachers face the challenge to provide opportunity for student questioning, while at the same time feeling pressure to cover the curriculum content. Teachers seem to be in need of support that enables them to guide *effective student questioning*, defined as guiding students to cover and master curriculum content by raising and inquiring into self-formulated SIS questions.

This thesis aims to develop and study the effects of such a support for primary school teachers. The main research question of this thesis is: How to support teachers to guide effective student questioning? Based on earlier research findings that mind mapping can support both the structure and freedom required for effective student questioning, this thesis explores how mind mapping can be integrated in the practical solution.

The research in this thesis can be characterized as educational design-based research. The sequence of studies follows the several stages of design-based research. First, a *validation* study identifies design principles for teacher guidance of effective student questioning in the literature. Second, in a *development* study a practical solution is developed on the basis of these design principles. Third, an *effectiveness* study researches the effects of the solution on student learning outcomes. Finally, an *implementation* study investigates if the solution is transferable to a variety of teachers in different primary school contexts.

CHAPTER 2

The validation study in Chapter 2 aimed to identify the design principles for developing a practical solution for teacher guidance of effective student questioning. The following research question was raised in this systematic qualitative literature review: *Which emergent themes with respect to guiding effective student questioning in primary school classrooms can be derived from the literature?*

To answer the research question, a data set of 36 articles was collected, using both study and report characteristics as inclusion criteria. All studies are peer-reviewed empirical reports on teacher guidance of student questioning in primary education pub-

lished since 1990. The data was analyzed in a three-by-three matrix, relating three phases of questioning (generating, formulating, and answering) to three perspectives on teacher guidance (teacher characteristics, instructional moves, and organization of student support).

The findings show that teachers combine a variety of teaching strategies to successfully guide the three phases of questioning. Four design-principles emerged, when analyzing the patterns how teachers effectively guide student questioning: (1) creating a supportive classroom culture for question generation by acknowledging potential in all questions, (2) defining a conceptual focus by means of a core curriculum, (3) establishing a sense of shared responsibility to collectively cover a core curriculum and organize peer-collaboration accordingly, and (4) visualizing student questioning and its relation to the curriculum.

CHAPTER 3

The development study in Chapter 3 aimed to develop a practical solution as well as theoretical understanding if and how this solution might support teacher guidance of effective student questioning. The research question was: *What is the relevance, practicality, and effectiveness of digital mind mapping in a principle-based scenario for guiding effective student questioning?*

To answer the research question, a multiple case design study was conducted, in which a prototype of principle-based scenario for teacher guidance of effective student questioning was developed, implemented, and evaluated in multiple iterations. Twelve teachers in nine classrooms participated in the development, implementation and evaluation of the scenario that consisted of five phases of guiding student questioning with mind mapping. Video-recordings of classroom activities and interviews with teachers were collected as the primary data. Analysis focused on fidelity of structure, operationalized as adherence to and duration of the five phases, and fidelity of process, operationalized as the relevance, practicality, and effectiveness of the scenario for guiding effective student questioning as perceived by the teachers.

The findings on structure fidelity show that teachers adhered to most of the phases and activities of the scenario within set time-constraints, with the exception of evaluating learning outcomes with students (Phase 5). The findings on process fidelity confirmed that in general 10 teachers perceived the scenario as relevant, practical, and effective for guiding effective student questioning. However, two teachers were critical of the practicality and effectiveness of mind mapping in the Knowledge Construction and Evaluation phases, because they noticed some students had difficulty with extending the classroom mind map and constructing their own mind maps. Overall, it was concluded from the results that the scenario generally supported most teachers in guiding effective student questioning.

CHAPTER 4

The aim of the effectiveness study in Chapter 4 was to determine the effectiveness of the scenario, operationalized as students attaining curricular goals by raising and exploring SIS questions. The research question was formulated as: *To what degree do students attain curricular objectives, operationalized as (1) learning a core curriculum, (2) elaborating on this core curriculum, and (3) refining the conceptual structure of their knowledge, when teachers guide student questioning by means of a mind map supported scenario?*

The study was set up as a single group pre-posttest design. Respondents were 276 students, aged between 8-12 years old, distributed over 10 classrooms in two primary schools. In each school teachers and students worked with the scenario on a self-chosen social science topic for a six week period. The teachers' expert mind map about the topic was assumed to represent the intended core curriculum. Pre and posttest student mind maps, teachers' expert mind maps, and classroom mind maps were collected as the primary data. To triangulate mind map tests, also a conventional pre and posttest multiple choice knowledge test was administered. Adherence to the scenario was checked by video recordings of classroom activities and product collection, such as mind maps, question sheets and other student products. Mind maps were analyzed for similarity to, and elaboration of, the core curriculum, and quality of structure. Correlations between the number and curricular focus of student questions and the learning outcomes, as measured by the mind maps, were calculated. Furthermore, correlations between the development of the classroom mind map and individual student mind maps were calculated.

Comparison between pre and posttests show that approximately 80% of the student mind maps improve in three ways: increased similarity with the core concepts mentioned in the expert mind map, elaboration on the core concepts, and improved quality of structure. About 7% of the mind maps remain in a status quo, and 15% of the mind maps show a decrease in either similarity, elaboration or quality of structure. At the same time, a significant moderate positive effect is observed in the results of the multiple choice knowledge test. Analysis of the SIS questions posed by the students shows no direct effect on individual learning outcomes, but does relate significantly to the development of collective knowledge in the classroom mind maps. Furthermore, the development of classroom mind maps significantly affects the attainment of core concepts and quality of structure in the student mind maps. Based on these results, it was concluded that the scenario is effective in terms of attaining curricular objectives for most students, and that especially the collective construction and extension of the classroom mind map in Phase 4 seems to play an important role in this.

CHAPTER 5

The aim of the implementation study in Chapter 5 was to determine to what extent the principle-based scenario for guiding effective student questioning was "robust", defined as the consistency of benefits when implemented by a variety of teachers, students, and settings. The following main research question was raised: *What is the robustness of a principle-based scenario for guiding effective student questioning?* Four sub questions were formulated. First, how do teachers perceive the scenario (intended curriculum)? Second, to what extent do teachers adhere to the essential and optional activities of the scenario (operational curriculum)? Third, to what extent do teachers experience support for their basic psychological needs (realized curriculum)? And finally, if and to what degree, do the differences in school contexts and teacher characteristics influence the teachers' decisions to either adopt or reject the scenario for further use?

Fifteen trainers introduced the scenario to 103 teachers in 23 schools. Schools differed from each other in terms of their organization of the curriculum, organization of grades, curriculum materials, and demographical characteristics. Teachers differed in terms of their age, gender, experience, work factor, and teaching grade. All teachers trialed the scenario in their classrooms for a six-week period. A questionnaire was administered, which measured the teachers' implementation decisions, use of activities of the scenario, perceived attributes of the scenario, experienced autonomy, competence, and relatedness, and various teacher and school characteristics. Findings on classroom activities and school variables were triangulated with product collection (such as mind maps, question sheets and student products) and school documents.

The findings show that the teachers perceive the scenario as having added value for guidance of student questioning and compatible with existing practices. Working with the scenario supports teacher feelings of autonomy, competence, and relatedness. Approximately 80% of all teachers would like to adopt the scenario for future use. About 55% of these teachers see opportunities to further adapt the scenario to their needs. Adherence to all phases of the scenario enhances the likeliness for adoption. Further exploration of the data shows that most school and teacher characteristics do not correlate with the decision to adopt or reject. Therefore, the conclusion of this study is that most teachers, despite differences in age, gender, grade, experience, and school contexts, are willing and able to guide effective student questioning with the scenario.

GENERAL CONCLUSION AND DISCUSSION

This thesis was set up to develop a practical solution for teacher guidance of effective student questioning, and to gain insight if and how this solution might work in classroom practice. The principle-based scenario, based on four design principles identified in a validation study, and developed and refined in close collaboration with teachers in the development study, proved not only to be effective for its intended use, but also transferrable to new school contexts. Present findings at least suggest that three factors seem to have contributed to support teachers in guiding effective student questioning: a) the four design principles applied in a five phase scenario were perceived as a relevant, practical, and effective scaffold for teacher guidance, b) the use of mind mapping as a complex visual tool proved to be supportive to put the design principles to practice, and c) the principle-based nature of the scenario, which provided both structure for guidance and to freedom to adapt content and processes to local needs and preferences, supported implementation.

However, one should keep in mind that the scenario is no panacea for effective student questioning, and requires active involvement of teachers and a conceptual approach to teaching. Moreover, new challenges have emerged for working with the scenario, such as organizing assessment for learning, and supporting progressive inquiry. We conclude that guidance of effective student questioning has a lot of potential for teaching and learning, which suggests a need for progressive inquiry into the topic, for this study offers only a few answers while raising much more new questions.

Samenvatting

Dit proefschrift gaat over de uitdaging voor leerkrachten in het basisonderwijs om leervragen van leerlingen een plaats te geven in hun onderwijs. Leervragen betreffen vragen die leerlingen zelf stellen, voortkomend uit persoonlijke belangstelling of verwondering en gericht op het willen weten en begrijpen. Het gebruik van leervragen van leerlingen in het onderwijs kan een positieve bijdrage leveren aan het leren van leerlingen. Zelf leervragen stellen versterkt de intrinsieke motivatie van leerlingen en bevordert de ontwikkeling van een onderzoekende houding. Zelf leervragen onderzoeken, bevordert de ontwikkeling van cognitieve en metacognitieve vaardigheden en ondersteunt zelfgestuurde kennisconstructie. Ook aan het lesgeven van leerkrachten kan het positief bijdragen. Leerkrachten kunnen leervragen gebruiken om meer zicht te krijgen op de voorkennis van leerlingen, te begrijpen hoe leerlingen redeneren, om onderzoeksactiviteiten op te starten en de betekenis van de leerstof voor de leerlingen te versterken.

Helaas blijken leervragen van leerlingen zeldzaam en blijven daardoor veel kansen voor het leren en lesgeven onbenut. Om dit te veranderen hebben leerkrachten een cruciale rol. Leerkrachten staan voor de uitdaging ruimte te bieden aan leervragen van leerlingen, terwijl zij ook de verantwoordelijkheid hebben leerstofdoelen te behalen. Leerkrachten hebben behoefte aan ondersteuning die hen in staat stelt “effectief vraaggestuurd onderwijs” te realiseren, gedefinieerd als onderwijs waarbij leerlingen eigen leervragen stellen en onderzoeken die bijdragen aan het leren van de beoogde leerstof.

Dit proefschrift heeft als doel ondersteuning te ontwikkelen en te onderzoeken die leerkrachten helpt in de begeleiding van effectief vraaggestuurd onderwijs. De centrale vraag in het proefschrift is: Hoe kunnen leerkrachten ondersteund worden in de begeleiding van vraaggestuurd onderwijs? Omdat eerder onderzoek heeft aangetoond dat mindmapping zowel de vrijheid voor leervragen als de structuur voor het borgen van leerstofinhouden kan bieden, wordt onderzocht of en op welke wijze mindmappen een rol kan spelen bij de begeleiding van effectief vraaggestuurd onderwijs.

De onderzoeksbenadering in dit proefschrift is ontwerponderzoek. De opbouw van de studies volgt de stadia van dit type onderzoek. Eerst worden in een *valideringstudie* de ontwerpprincipes voor de begeleiding van effectief vraaggestuurd onderwijs in de literatuur gezocht. Dan wordt in een *ontwikkelstudie* een praktische oplossing op basis van deze ontwerpprincipes ontwikkeld. Vervolgens onderzoekt een *effectiviteitstudie* de effecten van deze oplossing op de leeropbrengsten van de leerlingen. Tenslotte wordt in een *implementatiestudie* verkend of de ontwikkelde oplossing ook toepasbaar is voor een verscheidenheid aan leraren in verschillende basisscholen.

HOOFDSTUK 2

De valideringsstudie in hoofdstuk 2 heeft tot doel om de ontwerpprincipes te identificeren die nodig zijn om een praktische oplossing te ontwikkelen voor de begeleiding van effectief vraaggestuurd onderwijs. De volgende onderzoeksvraag werd gesteld in dit systematische kwalitatieve literatuuronderzoek: *Welke ontwerpprincipes kunnen in de literatuur worden gevonden ten aanzien van de begeleiding van effectief vraaggestuurd onderwijs?*

Om de onderzoeksvraag te beantwoorden zijn 36 studies geselecteerd op basis van zowel onderzoeks- als verslagskenmerken. Alle studies waren wetenschappelijke empirische onderzoeken naar de begeleiding van leervragen in het basisonderwijs, gepubliceerd na 1990. De studies zijn geanalyseerd aan de hand van een matrix, die de drie fasen in het vraagproces (oproepen, formuleren en beantwoorden) verbindt met drie perspectieven op leerkrachtbegeleiding (leerkrachtkenmerken, instructieactiviteiten en de ondersteuning van het vraagproces)

De resultaten tonen dat leerkrachten een verscheidenheid aan lesgevende strategieën combineren om leerlingen te begeleiden in de drie fasen van het vraagproces. Door de patronen in de leerkrachtbegeleiding te analyseren werden vier ontwerpprincipes geïdentificeerd: (1) creëer een ondersteunende klassencultuur door de waarde van elke vraag voor leren te benadrukken, (2) definieer een conceptuele focus voor de leervragen door het vaststellen van een kerncurriculum, (3) bevorder de gezamenlijke verantwoordelijkheid en samenwerking in de klas voor het verkennen en uitbreiden van het kerncurriculum, en (4) visualiseer de relatie van de leervragen en antwoorden met het kerncurriculum.

HOOFDSTUK 3

De ontwikkelstudie in hoofdstuk 3 had tot doel om zowel een praktische oplossing te ontwikkelen voor de begeleiding van vraaggestuurd onderwijs, als ook theoretisch inzicht te verwerven of en hoe deze oplossing leerkrachten zou kunnen ondersteunen. Gebaseerd op literatuur over het visualiseren van kennis in conceptmap en mindmaps is digitaal mindmappen in de praktische oplossing centraal gesteld. De onderzoeksvraag was: *Wat is de relevantie, haalbaarheid en effectiviteit van digitaal mindmappen in een scenario voor de begeleiding van vraaggestuurd onderwijs?*

Om de onderzoeksvraag te beantwoorden is een meervoudige case studie uitgevoerd waarin een prototype van een scenario voor de begeleiding van vraaggestuurd onderwijs werd ontwikkeld, geïmplementeerd en geëvalueerd in meerdere rondes. Twaalf leerkrachten in negen klassen namen deel aan de ontwikkeling, uitvoering en evaluatie van dit scenario, waarin mindmappen een centrale rol speelde in vijf opeenvolgende fases van vraaggestuurd onderwijs: voorbereiding, introductie, vragen stellen, kennisbouwen en evaluatie. Video-opnames van klassenactiviteiten en interviews met de leraren waren de primaire data. De analyse richtte zich op de *betrouwbaarheid van de structuur* en op *betrouwbaarheid van het proces*. De betrouwbaarheid van de structuur werd geoperationaliseerd als de mate van naleving van activiteiten in de vijf fases en gelijke tijdsduur. De betrouwbaarheid van het proces was geoperationaliseerd als de relevantie, haalbaarheid en effectiviteit van het scenario voor de begeleiding van vraaggestuurd onderwijs, zoals dit werd ervaren door de leerkrachten.

De resultaten tonen dat de leerkrachten de meeste activiteiten in de verschillende fases uitvoerden zoals beoogd. Tien leerkrachten gaven aan dat zij en hun leerlingen enthousiast waren over deze manier van werken in de klas, omdat het scenario relevant, haalbaar en effectief was voor de begeleiding van vraaggestuurd onderwijs. Twee leerkrachten waren positief over de eerste drie fases van het scenario, maar waren kritisch over de haalbaarheid en effectiviteit van mindmappen voor de fases van kennisbouwen en evaluatie. Deze twee leerkrachten vonden de effecten van de klassenmindmap op het gezamenlijk leren van leerlingen nog beperkt en zagen daarnaast dat sommige leerlingen moeite hadden met het tekenen van de eigen mindmaps. De resultaten tonen dat het scenario over het algemeen als een functionele ondersteuning werd ervaren in de vijf fases van de begeleiding van effectief vraaggestuurd onderwijs.

HOOFDSTUK 4

Het doel van de effectiviteitsstudie in hoofdstuk 4 was om te bepalen of in welke mate de leerlingen de leerstofdoelen behaalden door het stellen en beantwoorden van hun leervragen. De onderzoeksvraag was: *In welke mate halen leerlingen leerstofdoelen, geoperationaliseerd als (1) het leren van het kerncurriculum, (2) het uitbreiden van kerncurriculum en (3) het verfijnen van de conceptuele structuur van hun kennis, als leerkrachten vraaggestuurd onderwijs begeleiden met behulp van een scenario ondersteund door mindmappen?*

De onderzoeksmethode bestond uit de vergelijking van voor- en nametingen van de betrokken leerlingen. De onderzoeksgroep bestond uit 276 leerlingen, tussen de 8 en 12 jaar oud, verdeeld over 10 klassen in twee basisscholen. In elke school werkten de leerkrachten en leerlingen zes weken aan een zelfgekozen onderwerp met het scenario. De expertmindmap van de leerkrachten werd aangehouden als de visualisatie van het kerncurriculum voor het onderwerp. Leerlingmindmaps, expertmindmap en klassenmindmap werden voor en na het leerarrangement verzameld als de primaire data. Om de resultaten van de mindmaptoets te valideren is voor en na het leerarrangement ook een multiple choice kennistoets afgenomen. Naast voor- en nametingen zijn tijdens de uitvoering van het scenario in de klassen video-opnames gemaakt en leerlingproducten zoals mindmaps en werkbladen verzameld. De analyse van de leerlingmindmaps richtte zich op overeenkomsten met en uitbreiding van het kerncurriculum en de kwaliteit van de conceptuele structuur. Correlaties van het aantal vragen en de focus van de vragen (op kerncurriculum of uitbreiding) met de leeropbrengsten in de mindmaps zijn berekend. Daarnaast zijn de correlaties tussen de ontwikkeling van de klassenmindmap en individuele leerlingmindmaps onderzocht.

De vergelijking tussen voor- en nametingen toonde dat ongeveer 80% van alle leerlingmindmaps op drie manieren beter werden: er werden meer kernconcepten uit de expertmindmap gebruikt, het aantal uitbreidingen op de kernconcepten nam toe en de kwaliteit van de mindmapstructuur verbeterde. Ongeveer 7% van de mindmaps bleef min of meer hetzelfde en 15% van de mindmaps nam juist af in mate van overeenkomst met de expertmindmap, uitbreiding of kwaliteit van de structuur. Tegelijkertijd werd een significant matig positief effect geconstateerd in de multiple choice kennistoets. De analyse van de leervragen toonde geen correlatie met individuele leeruitkomsten, maar er was wel een significant effect op de ontwikkeling van de gezamenlijke klassenmindmap. Tevens had de ontwikkeling van de klassenmindmap een significant effect op het gebruik van kernconcepten en de kwaliteit van structuur in de leerlingmindmaps. Op basis van deze resultaten kon geconcludeerd worden dat het scenario een effectieve bijdrage levert aan het behalen van leerstofdoelen door een ruime meerderheid van de leerlingen. Hierbij lijkt vooral de gezamenlijke uitbreiding van de klassenmindmap een belangrijke rol te spelen.

HOOFDSTUK 5

Het doel van de implementatiestudie in hoofdstuk 5 was om te bepalen of, en in welke mate, het scenario voor de begeleiding van effectief vraaggestuurd onderwijs “robuust” was. Robuustheid is hier gedefinieerd als de consistentie van het scenario voor de begeleiding van vraaggestuurd onderwijs voor een verscheidenheid aan leraren in verschillende basisscholen. De centrale onderzoeksvraag was: *Wat is de robuustheid van het scenario voor de begeleiding van vraaggestuurd onderwijs?* Vier deelvragen werden geformuleerd. Ten eerste, hoe interpreteren leerkrachten het scenario (beoogd curriculum)? Ten tweede, in welke mate voeren de leerkrachten de essentiële en optionele activiteiten van het scenario uit (uitgevoerd curriculum)? Ten derde, in welke mate ervaren leerkrachten ondersteuning tijdens uitvoering van het scenario (gerealiseerd curriculum)? Ten slotte, hebben de verschillen tussen kenmerken van scholen en leerkrachten invloed op de keuze van leerkrachten om het scenario wel of niet in de toekomst te blijven gebruiken?

Het scenario is door 15 experts in een korte training geïntroduceerd aan 103 leraren op 23 scholen. De scholen verschilden van elkaar op aspecten als: organisatie van het curriculum, indeling van klassen, gebruik van leermiddelen en demografische kenmerken. De leerkrachten verschilden van elkaar op kenmerken als: leeftijd, geslacht, ervaring, werktijdfactor en groep waarin ze lesgeven. Alle leerkrachten hebben het scenario gedurende zes weken uitgeprobeerd in hun eigen klas. In een vragenlijst werden de leerkrachten gevraagd naar: verschillende school- en leerkrachtkenmerken; hun uitvoering van activiteiten; hun waardering van kenmerken van het scenario; de ervaren autonomie, relatie en competentie; en de keuzes qua toekomstig gebruik. De resultaten ten aanzien van uitvoering van het scenario en de schoolkenmerken werden getrianguleerd met verzamelde leerlingproducten en schooldocumenten.

De resultaten tonen dat de leerkrachten het scenario waarderen omdat het meerwaarde heeft voor de begeleiding van vraaggestuurd onderwijs en aansluit bij de bestaande praktijk. Het werken met het scenario ondersteunt de gevoelens van autonomie, relatie en competentie van de leerkrachten. Ruim 80% van de leerkrachten geeft aan het scenario in de toekomst te blijven gebruiken. Ongeveer 55% van de leerkrachten ziet mogelijkheden om het scenario nog verder naar hun hand te zetten. De uitvoering van alle fasen van het scenario hangt samen met de waarschijnlijkheid van toekomstig gebruik: leerkrachten die alle fasen van het scenario uitvoeren (57%) geven vaker aan het scenario in de toekomst te willen gaan gebruiken dan leraren die niet alle fasen uitvoeren. Nadere verkenning van de resultaten toont dat de keuze voor toekomstig gebruik vrijwel niet beïnvloed wordt door de school- en leerkrachtkenmerken. Daarom is de conclusie dat een ruime meerderheid van de leerkrachten in deze studie, ongeacht verschillen in leeftijd, geslacht, ervaring en schoolcontext, bereid en in staat zijn om vraaggestuurd onderwijs met het scenario te begeleiden.

ALGEMENE CONCLUSIE EN DISCUSSIE

Dit proefschrift had als doel een praktische oplossing voor de begeleiding van vraaggestuurd onderwijs te ontwikkelen en inzichten te verkrijgen of en hoe deze oplossing zou werken in de klassenpraktijk. Het scenario, gebaseerd op de vier ontwerpprincipes uit de valideringstudie en ontwikkeld en verfijnd in nauwe samenwerking met de leerkrachten in de ontwikkelstudie, bleek niet alleen effectief voor het beoogde doel maar ook toepasbaar in andere schoolcontexten. De resultaten suggereren dat drie factoren leraren hebben ondersteund in de begeleiding van vraaggestuurd leren: a) de vier ontwerpprincipes toegepast in een vijf-fasen scenario werden beschouwd als relevant, praktisch en effectief voor de leerkrachtbegeleiding, b) mindmapping bleek als visueel gereedschap in staat om de ontwerpprincipes concreet te ondersteunen, en c) het op ontwerpprincipes gebaseerde scenario bood zowel de structuur voor de begeleiding, als de vrijheid om inhoud en processen aan te passen aan lokale behoeften en voorkeuren.

Hierbij merken wij op dat het scenario geen wondermiddel is voor de begeleiding van vraaggestuurd leren. Het gebruik vraagt van leerkrachten een actieve betrokkenheid, een open onderzoekende houding en een conceptuele benadering van lesgeven. Bovendien hebben zich nieuwe uitdagingen aangediend in het werken met het scenario, zoals: Hoe kunnen leerkrachten voortschrijdend onderzoek ondersteunen, waarin de antwoorden op leervragen tot nieuwe leervragen leiden? Hoe kunnen leerkrachten het meest efficiënt leerlingen gezamenlijk verantwoordelijk maken voor de collectieve kennisconstructie? Hoe kunnen leerkrachten leerlingen betrekken bij het evalueren van eigen leervorderingen? We concluderen dat vraaggestuurd onderwijs veel mogelijkheden biedt voor zowel leren als lesgeven, maar dat voortschrijdend onderzoek nodig is omdat gevonden antwoorden altijd weer nieuwe vragen oproepen!

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Harry Stokhof, Wijchen, 1 juni 2018

Short biography of the author

Harry Stokhof was born on the 25th of December 1965 in Amsterdam, the Netherlands. After receiving his gymnasium Beta diploma from the Thomas A Kempis College in Zwolle in 1984, he started studying History at the University of Groningen. In 1986, Harry continued his studies at the University of Amsterdam and the University of Leiden, studying Modern Asian History, Philosophy and Chinese Language. In 1990 Harry received his Master Degree and a scholarship to study in the Chinese People's Republic for several months.

Inspired by the birth of his son, Harry decided to change his career and entered an accelerated course at Teachers' College for Montessori Primary Education at the Amsterdam University of Applied Sciences in 1993. After his graduation, Harry worked as a primary school teacher at a Montessori primary school, from 1995 to 2005. As a primary school teacher, Harry experimented with his colleagues to develop more engaging forms of social science education with the use of ICT. Harry collaborated with researchers and teachers from HAN University of Applied Sciences in Nijmegen.

In 2005 Harry was asked to join Teachers' College of HAN University of Applied Sciences as a teacher educator, and also joined its Centre of Expertise for Teaching and Learning as a junior researcher. Harry collaborated on several research projects about inquiry-based education in primary and teacher education. In 2011, he received a 70.000 euro grant of the Kennisnet Foundation to investigate the potential of digital mind mapping for teacher guidance. In the same year, Harry received a grant of HAN University of Applied Sciences to conduct a PhD research into the topic of teacher guidance of student questioning. Harry combined the PhD project with his work as a teacher educator and curriculum developer.

For his contributions to the practice-based research program at HAN University of Applied Sciences, he was elected as "HAN Researcher of the Year" in 2014. At the 2016 Conference of the European Association for Practitioner Research on Improving Learning in Porto, Harry received the "Best Research and Practice Project Award" for his work on teacher guidance of effective student questioning. Harry continues his work as a teacher educator, researcher, and educational designer aiming to connect the realms of teacher education, educational research, and school development.

List of Publications

ACADEMIC JOURNALS

Stokhof, H. J. M., De Vries, B., Bastiaens, T., & Martens, R. (2018). *To Adopt or reject? Testing the robustness of a scenario for guiding effective student questioning*. Manuscript submitted for publication.

Stokhof, H. J. M., De Vries, B., Bastiaens, T., & Martens, R. (2018). Using mind maps to make student questioning effective: Learning outcomes of a principle-based scenario for teacher guidance. *Research In Science Education*. Advance online publication. doi:10.1007/s11165-017-9686-3

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Stokhof, H. J. M., De Vries, B., Bastiaens, T., & Martens, R. (2017). *Elke vraag heeft potentie. Een scenario voor vraaggestuurd leren* [Every question has potential. A scenario for teacher guidance of question-driven learning]. *Didactief, 47(*1-2), 54-55.

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Stokhof, H. J. M. (2015). *Creativiteit en de kunst van het vragen stellen* [Creativity and the art of posing questions]. *Chronos*, *10*, 20-24.

Stokhof, H. J. M. (2014). *Intrinsieke motivatie en vraaggestuurd leren* [Intrinsic motivation and question-driven learning]. *Mensenkinderen, 144*, 19-21.

PRESENTATIONS

Stokhof, H. J. M., De Vries, B., Martens, R., & Bastiaens, T. (2017, December). *To Adopt, Adapt or Reject? Testing a scenario for guiding "effective student questioning".* Present and discuss session at the Conference of the European Association for Practitioner Research on Improving Learning [EAPRIL], Hämeenlinna, Finland.

Stokhof, H. J. M., De Vries, B., Martens, R., & Bastiaens, T. (2016, November). *A Quest for Autonomous Thinkers and Learners.* Keynote presentation at the Conference of the European Association for Practitioner Research on Improving Learning [EAPRIL], Porto, Portugal.

Stokhof, H. J. M., & Fransen, P. (2016, June). *"Let's focus on exploration". Developing professional identity as global teachers in a question-driven practicum.* Paper presentation at the British Educational Research Association [BERA] Conference on Global Citizenship, Worcester, United Kingdom.

Stokhof, H. J. M., De Vries, B., Martens, R., & Bastiaens, T. (2015, September). *Supporting Teachers and Students by Digital Mind Mapping to Attain the Curriculum in Question-Driven Learning.* Present and discuss session at the Congress of the European Educational Research Association [EERA], Porto, Portugal.

Stokhof, H. J. M., De Vries, B., Martens, R., & Bastiaens, T. (2014, September). *Leerstofborging in vraaggestuurd leren door digital mindmappen* [Attaining curricular objectives in question-driven learning]. Keynote at the Pabo Conferentie [Teacher Educators Conference for Primary Education], Utrecht, The Netherlands.

Stokhof, H. J. M., De Vries, B., Martens, R., & Bastiaens, T. (2013, November). *Supporting question-driven learning with digital mindmapping*. Paper presentation at the Conference of the European Association for Practitioner Research on Improving Learning [EAPRIL], Bienne, Switzerland.

Stokhof, H. J. M., De Vries, B., Martens, R., & Bastiaens, T. (2013, May). *Leerstofborging in vraaggestuurd leren* [Attaining curricular objectives in question-driven learning]. Round Table, Onderwijs Research Dagen, Brussels, Belgium.

Stokhof, H. J. M., Sluijsmans, D., van Vlokhoven, H., & Peters, M. (2012, June). *Naar dynamisch en gestructureerd vraaggestuurd leren met digitale mindmaps* [Towards dynamic and structured question-driven learning supported by digital mind maps]. Paper presentation at the Kennisnet Symposium, Onderwijs Research Dagen, Wageningen, The Netherlands.

Stokhof, H. J. M., Sluijsmans, D., & Uden van, E. (2011, October). *Fostering Inquiry Based Learning by Digital Mind Maps.* Researcher – Practitioner Session at the Conference of the European Association for Practitioner Research on Improving Learning [EAPRIL], Nijmegen, The Netherlands.

Stokhof, H. J. M., & De Vries, B. (2009, November). *Concept mapping as a tool for Inquiry based learning.* Paper presentation at the Conference of the European Association for Practitioner Research on Improving Learning [EAPRIL], Trier, Germany.

POSTER PRESENTATIONS

Stokhof, H. J. M., De Vries, B., Martens, R., & Bastiaens, T. (2016, November). *Scenario for teacher guidance of effective student questioning.* Poster presentation at the Conference of the European Association for Practitioner Research on Improving Learning [EAPRIL], Porto, Portugal.

Stokhof, H. J. M., De Vries, B., Martens, R., & Bastiaens, T. (2016, Februari). *Scenario voor de begeleiding van vraaggestuurd leren* [Scenario for teacher guidance of question-driven learning]. Poster presentation at the Congres van Vereniging van Lerarenopleiders [Teacher Educators Congres], Brussel, Belgium.

Stokhof, H. J. M., Sluijsmans, D. & van Vlokhoven, H. (2011, June). DYNAMIND: *Dynamische mindmapping in gestructureerd vraaggestuurd leren* [Dynamic mind mapping to support structured question-driven learning]. Poster presentation at the Onderwijs Research Dagen, Maastricht, The Netherlands.

WORKSHOPS

Stokhof, H. J. M., De Vries, B., Martens, R., & Bastiaens, T. (2018, April). *Vraaggestuurd leren begeleiden met mindmaps* [Guiding Effective Student Questioning by Mind Mapping]. Workshop at Conferentie Educatie Samen Opleiden vanuit Nieuwsgierigheid, HAN University, Nijmegen, The Netherlands.

Stokhof, H. J. M., De Vries, B., Martens, R., & Bastiaens, T. (2018, March). *Mind Map Our Way into Effective Student Questioning: A Principle-based Scenario.* Workshop at the MinT Study Day of the Karel de Grote University of Applied Sciences, Antwerp, Belgium.

Stokhof, H. J. M., De Vries, B., Martens, R., & Bastiaens, T. (2017, December). *Mind Map Our Way into Effective Student Questioning: A Principle-based Scenario.* Workshop at the Conference of the European Association for Practitioner Research on Improving Learning [EAPRIL], Hämeenlinna, Finland.

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Stokhof, H. J. M., De Vries, B., Martens, R., & Bastiaens, T. (2017, March). *Vraaggestuurd leren als hbo didactiek* [Question-driven learning as a method to engage students at the University of Applied Sciences]. Workshop for Faculty of Economy and Management of the HAN University of Applied Sciences, Arnhem, The Netherlands.

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Stokhof, H. J. M., De Vries, B., Martens, R., & Bastiaens, T. (2016, September). *Mind Map Our Way into Effective Student Questioning: A Principle-based Scenario.* Workshop at the Conference of the Association for Teacher Education in Europe [ATEE], Eindhoven, The Netherlands.

Stokhof, H. J. M., De Vries, B., Martens, R., & Bastiaens, T. (2016, March). *Samen bouwen aan kennis door vraaggestuurd leren* [Collective knowledge construction by means of question-driven learning]. Workshop at the Conference of Stichting Katholiek Onderwijs Enschede [Foundation for Catholic Education Enschede], Enschede, The Netherlands

Stokhof, H. J. M., De Vries, B., Martens, R., & Bastiaens, T. (2015, January). *Samen bouwen aan kennis door vraaggestuurd leren* [Collective knowledge construction by means of question-driven learning]. Workshop at the Winter School of the Wetenschapsknooppunt [Science Hub] Radboud University, Nijmegen, The Netherlands.

Stokhof, H. J. M., & Holthuis, P. (2015, March). *W&T in het OJW onderwijs? Onderzoekend en vraaggestuurd leren en geschiedenis* [Science and Technology in the Social Sciences. Inquiry-based and question-driven learning in History education]. Workshop at the Wetenschapsknooppunt [Science Hub] Utrecht University, Utrecht, The Netherlands.

Stokhof, H. J. M., Artz, R., Lamers, E., & Prins, D. (2014, November). *Vraaggestuurd leren: de oplossing om de 21ste eeuwse vaardigheden te concretiseren in de klas?* [Question-driven learning. The solution to implement 21th Century Skills in the classroom?]. Workshop at the Regionale Onderwijsconferentie [Regional Educational Conference], Han University of Applied Sciences, Nijmegen, The Netherlands.

Stokhof, H. J. M., De Vries, B., Martens, R., & Bastiaens, T. (2014, September). *Leerstofborging in vraaggestuurd leren door digital mindmappen* [Attaining curriculum objectives in question-driven learning by digital mind mapping]. Workshop at the Pabo Conferentie [National Teacher Educators Conference for Primary Education], Utrecht, The Netherlands.

Stokhof, H. J. M., Sluijsmans, D., & van Vlokhoven, H. (2012, February). *DYNAMIND: Naar gestructureerd dynamisch mindmapping in vraaggestuurd leren* [Towards structured dynamic mind mapping in question-driven learning]. Workshop at the Congres van Vereniging van Lerarenopleiders [Teacher Educators Congress], Antwerp, Belgium.

Stokhof, H. J. M., Sluijsmans, D. & van Vlokhoven, H. (2011, March). *DYNAMIND: Dynamische mindmapping in gestructureerd vraaggestuurd leren* [Dynamic mind mapping to structure question-driven learning]. Workshop at the Congres van Vereniging van Lerarenopleiders [Teacher Educators Congress], Noordwijkerhout, The Netherlands.

MANUALS

Stokhof, H.J.M., De Vries, B. Martens, R., & Bastiaens (2017). *Scenario for guiding effective student questioning by means of (digital) mind mapping: A teachers manual.* Nijmegen, The Netherlands: HAN University. doi:10.13140/RG.2.2.24260.94081

AWARDS

Best Practice and Research Project Award 2016, European Association for Practitioner Research on Improving Learning [EAPRIL], Porto, Portugal.

HAN Researcher of the Year 2014, HAN University of Applied Sciences, Arnhem, The Netherlands.

Best Poster Award, Onderwijs Research Dagen 2011, Maastricht, The Netherlands.